Integration of a Road Surface Model into NWS Operations

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Snowy, slushy, and icy roads are responsible for more than 580,000 vehicle crashes, 180,000 injuries, and 2,100 fatalities each year in the United States. The expenses associated with maintaining passable roads during wintry weather are enormous: state and local agencies spend $2.3 billion annually on snow and ice control. Furthermore, these mitigating actions can be rendered insufficient by a number of factors (e.g., an inaccurate forecast), resulting in economic losses as traffic is slowed.

For the National Weather Service (NWS), the above represents an opportunity to further enhance our mission: ". . . the protection of life and property and the enhancement of the national economy." Improving our ability to communicate the threat of hazardous conditions on roadways to our users conforms to the new NWS Strategic Plan, which calls for an increased focus on decision support services (DSS) to local emergency managers and the public in advance of, and during, high-impact events.

To objectively highlight the impacts that adverse weather may have on road surface conditions, it is important that the impacts be assessed independently from the perceived intensity of the event producing them. For example, storm systems characterized as being strong due to a variety of factors (e.g., low central pressure, strong vertical lift, or intense precipitation rates) do not always result in deteriorating or hazardous road surface conditions. Other factors, such as sufficiently cold road surface temperatures, must be in place if the conditions are to impact public safety. The use of specific criteria to classify events (e.g., 6 inches of snow in 12 hours is a winter storm), while often useful, does not account for the other environmental factors influencing road surface conditions. Societal factors also play a role: two inches of accumulating snow on road surfaces during rush hour likely constitutes a high-impact event, but two inches of snow melting on contact with the road likely does not.

While we trust operational forecasters to be aware of the relevant societal factors, the task of integrating over the wide range of environmental factors that contribute to road surface conditions at one location, let alone many, is much to ask. Rather, in the fast-paced environment of a forecast office, an objective tool is needed to do this work so that the forecaster can focus on synthesizing meteorological information, merging it into a good forecast, assessing the societal impacts, and then communicating those impacts to our users. This information will not be distributed by the NWS, but will be used to aid in situational awareness and the enhancement of existing products.

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ROAD SURFACE MODEL. The Model of the Environment and Temperature of Roads (METRo) forecasts road surface conditions by physically resolving the complex interactions between the environment and the road surface, including the radiation budget and phase changes of any moisture on the road surface. Developed at Environment Canada, METRo aims to produce accurate point forecasts over an extensive network of road weather information system (RWIS) stations. In a study conducted by the National Center for Atmospheric Research (NCAR), METRo generally outperformed two other road surface models under a variety of atmospheric conditions.

METRo relies on three types of data as input: site-specific metadata (road surface type and the makeup of its underlying layers), past observations (including road surface temperature and optionally, subsurface temperature), and an atmospheric forecast consisting of pressure, temperature, dewpoint, wind speed, cloud cover, and precipitation at a specific point.

The forecast data can either be supplied manually by a user or retrieved automatically from a gridded dataset. Currently, we use data from the National Digital Forecast Database (NDFD), a repository of gridded NWS forecast products, to supply METRo with all forecast variables, except for pressure, which is obtained from the 12-km North American Mesoscale model (NAM). The NDFD data are interpolated to a temporal resolution of one hour before being passed to METRo. Past observations are obtained through *Clarus,* an initiative of the Federal Highway Administration and the U.S. Department of Transportation's Intelligent Transportation Systems Joint Program Office. *Clarus* assimilates RWIS data from many state networks, performs quality checking, and then makes data available to interested users. Site-specific metadata pertaining to roadway surface type and depth is obtained through communication between the NWS office and the local Department of Transportation.

METRo consists of three primary modules, each evaluating one of the following phenomena: the surface energy balance, conduction of heat through the road material, and the accumulation of precipitation at the road surface. Each of these is briefly summarized below; for a more thorough discussion, see the model description by Crevier and Delage in their 2001 *Journal of Applied Meteorology* article.

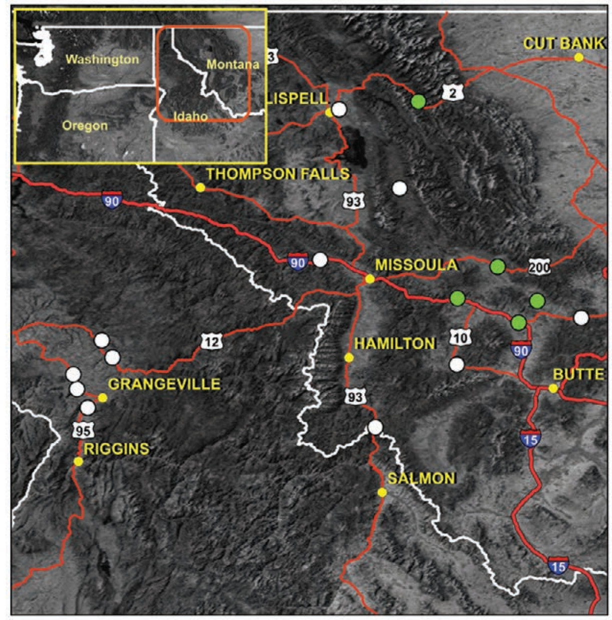
The surface energy balance module determines the residual of seven contributing terms: incoming shortwave energy, incoming longwave energy, outgoing longwave energy, sensible heat flux, latent heat flux, the flux associated with phase changes of precipitating water, and an anthropogenic flux. The anthropogenic flux is related to traffic volume and represents the heating from combustion, as well as from friction between tires and the road surface. Since the anthropogenic flux is not explicitly known, METRo adjusts the value each day by 1.0 W m^{-2} for every degree Celsius in the mean temperature bias during the previous night (nighttime temperatures are used because solar forcing is not a dominant mechanism).

The road heat-conduction module uses one-dimensional diffusion (for relevant equations, see Crevier and Delage 2001) to solve for temperature throughout the road material, which is divided into numerous layers. The number and depth of these layers are determined by the type of road (e.g., road versus bridge). For typical roads (not bridges or overpasses), a variable resolution in layer thickness is chosen such that the resolution between layers is higher near the road surface and lowers farther away (deeper underground). For bridges and overpasses, a uniform resolution of 0.01 m is used for each layer, with the number of layers being determined by the road thickness. This approach is well suited to these types of roads, as the ambient air temperature on either side of the elevated structure strongly influences road surface temperature.

The precipitation accumulation module allocates precipitation to one of two reservoirs, liquid or frozen, based on road surface temperature. Both water runoff and snow removal due to traffic and/or maintenance are parameterized through the use of an exponential relaxation function (see Crevier and Delage 2001). This function does not produce snow removal if the amount in the frozen precipitation reservoir is $\leq$ 1.0 kg m^{-2}, but if the amount is greater, it produces snow removal until this value is reached, effectively simulating the removal of snow by traffic and maintenance operations. However, METRo does not explicitly resolve for preventative anti-icing measures or the passage of snow plows, which will dramatically reduce the amount of snow and/or ice on the road surface. In this sense, METRo accumulations of frozen precipitation are best viewed as potential scenarios assuming that no action is taken.

INITIAL RESULTS. Beginning in mid-November 2011, the NWS forecast office in Missoula began archiving METRo forecasts for RWIS stations across northern Idaho and western Montana. These forecasts were initialized twice daily, at 1000 and 2100 UTC, and were run for a period of 30 hours. We made use of this data to conduct a limited verification study, to help us evaluate the operational usefulness of METRo road surface temperature forecasts (hereafter, roadcasts). This study spans the period from mid-November 2011 through March 2012, a time of year when winter road conditions across the region can be particularly treacherous. Of the 16 RWIS stations for which METRo forecasts were archived, there were many for which we could not obtain the necessary archived road surface temperature observations to perform verification, and results are shown only for the 5 stations where such observations were available (Fig. 1).

Fig. 1. Location of RWIS stations for which METRo roadcasts were archived and used (green) or not used (white) in our verification, centered on northern Idaho and western Montana. White lines denote state borders, red lines denote roadways, and yellow circles denote selected communities throughout the area. The background image is terrain.



For both initialization times at each station, the mean absolute error (MAE) and mean error (ME) of METRo roadcasts at all forecast hours were computed. The same was done for the gridded air temperature forecasts, which are passed from the NDFD to the model during initialization. Differences in results between RWIS stations were generally small, with a few exceptions. For this reason, we present results averaged over all stations, but caution that results at individual locations may not follow the same pattern of results presented here.

The MAE of METRo roadcasts is < 3°C at all verifying road surface temperatures in the range of ±10°C, and is smallest when road surface temperatures verify near or just above 0°C (Fig. 2). Although the difference in MAE between results near and further away from 0°C is on the order of only a degree, this result is pertinent and very encouraging, since

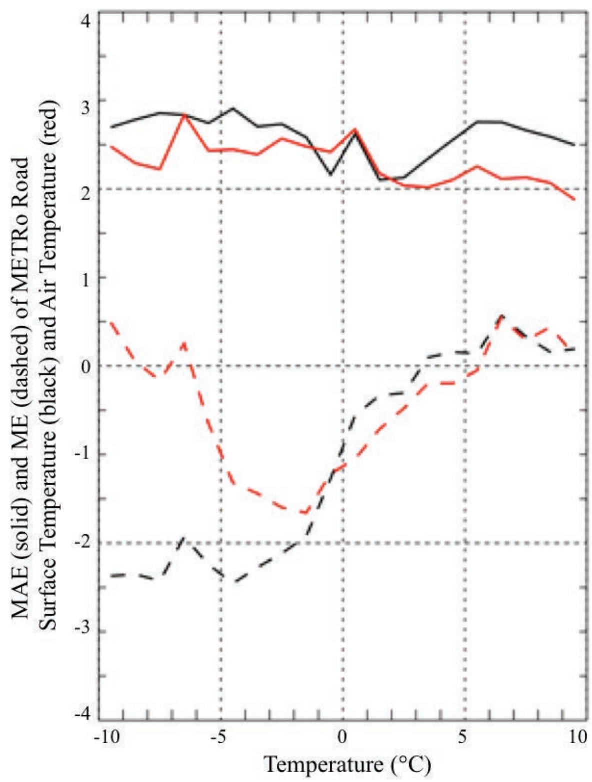


Fig. 2. MAE and ME of METRo road surface temperature (black) and gridded air temperature (red) forecasts vs verifying road surface temperature for five RWIS locations. Solid lines show the MAE and dashed lines show the ME. Results are averaged over all sites, all months (mid-Nov 2011–Mar 2012), and both model initializations (1000 and 2100 UTC).

our principal concern is model performance under conditions where precipitation type and/or the phase of water at the road surface are difficult to predict (i.e., when road surface temperatures are near 0°C). We are less concerned with model performance at road surface temperatures of ±5°C or greater. The ME, or bias, of METRo roadcasts varies with the sign of verifying road surface temperature. At verifying road surface temperatures below 0°C, METRo roadcasts exhibit a well-defined negative bias, but this bias is much reduced, or even nonexistent, at verifying road surface temperatures above 0°C.

Examining the relationship between METRo roadcast error and the diurnal cycle for both the 1000 and 2100 UTC run initializations, we find that the MAE is generally smallest during the early evening (approximately 0000 UTC), increases through the overnight and into the morning, and reaches a maximum in the late morning or afternoon (Fig. 3). The seasonality of these errors (not shown) exhibits substantial monthly variation: for example, the larger morning and afternoon MAE is primarily the result of large errors occurring at these times during February and March. Throughout the diurnal cycle, METRo roadcast errors are characterized by a highly variable cold bias of up to –3.5°C, with the exception of errors occurring during the late afternoon, when a warm bias is predominant.

The biases of METRo roadcasts may be partially due to errors in the gridded air temperature forecasts being passed from the NDFD to the model at initialization. Notice the remarkable proportionality between the biases of METRo roadcasts and gridded air temperature throughout the diurnal cycle (Fig. 3). This suggests that at least a portion of METRo roadcast

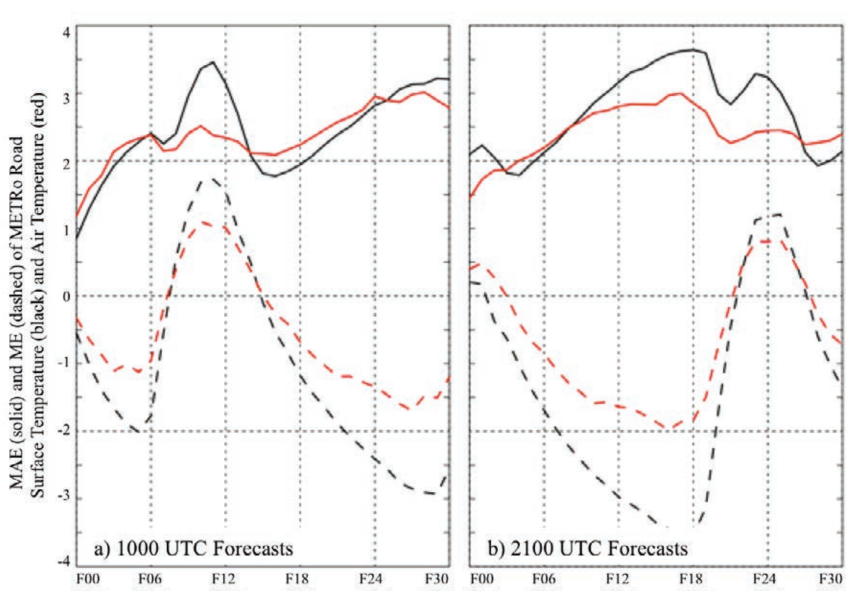


Fig. 3. MAE and ME of METRo road surface temperature (black) and gridded air temperature (red) forecasts vs forecast hour (or time of day) for the (a) 1000 and (b) 2100 UTC model initializations for five RWIS locations. Solid lines show the MAE and dashed lines show the ME. Results are averaged over all sites and all months (mid-Nov 2011–Mar 2012).

error can be attributed to forecast errors in the NDFD. Given the observed pattern of biases in both METRo roadcasts and gridded air temperature (night/morning cool biases and late afternoon warm biases), it seems plausible that gridded forecasts made during the timeframe of our study generally did not account for enough cloud cover, resulting in air temperature forecasts that were too strongly forced by radiation. However, because the RWIS sensors used in our study are not outfitted with ceilometers, it is difficult to objectively evaluate the relationship between METRo roadcast errors and cloud cover.

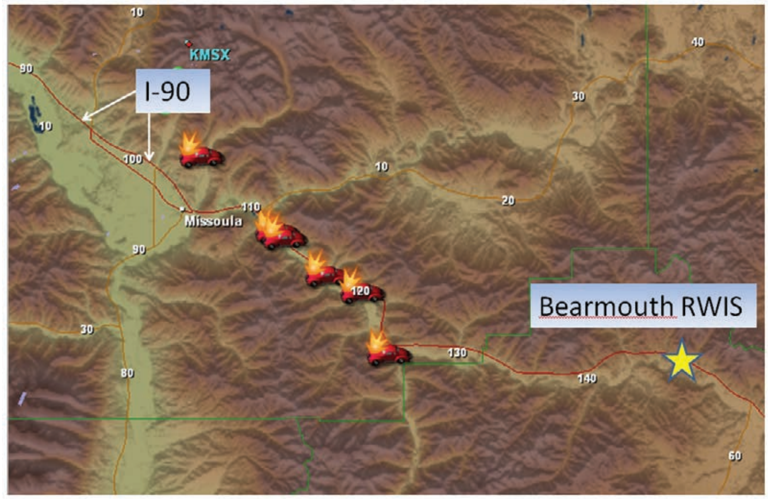


Fig. 4. Location of roadway crashes (red cars) during the morning hours of 8 Jan 2012. The nearest RWIS station (Bearmouth) is indicated by the yellow star. I-90 is located northwest to southeast through the Missoula area. White numbers are mile markers. The background image is terrain. The location of the KMSX 88D Doppler radar is also shown. Note that the distance between RWIS sites can be large and METRo output is for a point, not the entire roadway.

OPERATIONAL EXAMPLE.

Early on the morning of 8 January 2012, a series of crashes occurred on Interstate 90 (I-90) near Missoula, Montana (Fig. 4). The crashes were a result of light freezing drizzle, which accumulated on the roadway, creating treacherous driving conditions. First responders to the crash locations were hampered by the driving conditions, as well as a power outage caused by a vehicular crash which damaged a power pole. The most serious incident was the rollover on I-90 of a commercial bus, resulting in 33 injuries and 2 fatalities. Area hospitals described the incident as the worst "large-scale mass-injury incident" since a chemical spill in 1996 (as published in the *Missoulian* newspaper, January 9, 2012).

The forecasting of freezing drizzle is nearly always a difficult task. This very light precipitation is often poorly depicted in numerical weather models and is often produced by subtle lifting mechanisms. The METRo forecast for the morning of January 8 indicated that the road surface temperature would likely be about −6°C. Therefore, if rain or drizzle were anticipated for the morning of January 8, it would clearly be a freezing precipitation event. Indeed, light liquid precipitation did develop during the overnight hours, resulting in treacherous driving conditions just after dawn.

For the NWS in Missoula, METRo has been beneficial to meteorologists in determining the potential impact of weather systems on area roads and to help determine when road conditions may affect public safety. The model also serves as a learning tool for forecasters by depicting just how quickly the road surface temperature can cool to 0°C or below, resulting in negative impacts that would not otherwise have been anticipated. In addition, the METRo forecasts provide guidance on when road temperatures will begin to rise above freezing, at which point road conditions often improve rapidly. While no specific products are issued based solely on METRo output, it does provide additional data that can be used to forecast the impact of weather systems on communities.

SUMMARY. Each year, hazardous driving conditions arising from wintry weather lead to vehicle crashes causing injuries and fatalities, property damage, and economic disruption to communities. The NWS has a mission to mitigate these public impacts through better forecasts and the provision of decision support services (DSS) to core partners, and METRo offers an opportunity for us to make a big stride forward in this area. Output from METRo can be used to gauge the potential hazards developing during certain weather events, allowing NWS forecasters to raise awareness when high-impact weather approaches. We note that METRo forecasts are only valid at single points and may not be useful even at short distances if there are changes in elevation, road surface, or even past conditions. Additionally, certain localized effects such as shading are not resolved by METRo, which can result in inaccurate roadcasts. Locally experienced forecasters are needed to recognize how these seemingly innocuous, point-specific details can cause real conditions to differ from METRo output.

It should be noted that the results discussed above are limited in scope, being obtained during a 4.5-month period over a geographically limited area. During the 2012–13 cool season, we will conduct a more extensive analysis of METRo performance across the western United States. In addition to expanding the geographic scope, we aim to perform a more rigorous investigation into the sources of METRo roadcast error.

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FOR FURTHER READING

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