A Comparison of Road Temperature Models: FASST, METRo, and SNATHERM

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Acronyms

ASOS – Automated Surface Observing System  
CRREL – Cold Regions Research & Engineering Laboratory  
DIA – Denver International Airport  
ESS – Environmental Sensing Station  
FAQ – Frequently Asked Questions  
FASST – Fast All-season Soil Strength  
FHWA – Federal Highway Administration  
MDSS – Maintenance Decision Support System  
MDT – Mountain Daylight Time  
MST – Mountain Standard Time  
METRo – Model of the Environment and Temperature of Roads  
NCAR – National Center for Atmospheric Research  
OS – Operating System  
RWIS – Road Weather Information System  
RWFS – Road Weather Forecast System  
Z – Zulu — Equivalent to Coordinated Universal Time (UTC)
1. Background

The Maintenance Decision Support System (MDSS) is designed to provide weather and road condition forecasts, along with treatment recommendations, in support of winter maintenance operations. The treatment recommendations produced by the system are highly dependent on the predicted weather and its anticipated impact on pavement conditions. The Federal Highway Administration (FHWA) prototype MDSS relies on several weather forecast models to create a consensus forecast of atmospheric conditions, while one surface energy balance model is used to generate forecasts of road temperature, as well as snow depth on the road. In conjunction with weather forecast data, these road condition forecasts are used to calculate the effects of actual and potential chemical applications on the road surface. The current implementation of the MDSS uses a road temperature model known as SNTHERM. SNTHERM is a one-dimensional energy and mass balanced model, written by Rachel Jordan at the U.S. Army Corps of Engineers, Cold Regions Research & Engineering Laboratory (CRREL) in the 1980s. Rachel Jordan retired from CRREL on August 1, 2004. Dr. Susan Frankenstein of CRREL is now the point of contact for SNTHERM. CRREL has elected to no longer actively maintain SNTHERM, as a newer road temperature model with similar skill has been developed by CRREL. As a result, the MDSS will need to find a replacement road temperature model to be included in its releases to the public sector. The road temperature model that replaces SNTHERM will need to be supported by its authors simply because neither NCAR nor the FHWA have intimate knowledge of the model.

This study evaluates two potential replacement road temperature models. Criteria include forecast performance, code stability, support, efficiency, and ease of use. The replacement model must produce forecasts with skill equal to or better than SNTHERM. SNTHERM’s forecasts are the benchmark for this accuracy. Due to time constraints, the forecast skill could not be evaluated over multiple seasons of data. Instead, only selected test cases are evaluated. The ease of use criterion is targeted towards ensuring that the users will be able to take the road temperature model and easily incorporate it into their operational decision support systems. The selected model should be well documented and supported.

The two road temperature models being evaluated are CRREL’s new energy balance model called the Fast All-season Soil Strength (FASST) model and a Canadian energy balance model called the Model of the Environment and Temperature of Roads (METRo). FASST was developed at CRREL to replace SNTHERM, with a significant portion of the code taken from SNTHERM (Frankenstein and Koenig 2004). METRo was developed by Environment Canada (Crevier and Delage 2001) and has been used operationally since 1999.
2. Ease of Use

The source code for both FASST and METRo can easily be downloaded via an ftp or web interface.

A. Operating Systems

1. FASST was developed for Windows, and it can be downloaded as an executable for use on the Windows operating system. This avoids the need for the user to compile any code. However, the FASST source code must be slightly modified for any use other than the default manual interface. The FASST code compiled and ran with similar results on a Linux OS platform. The code needed to be modified because of the Windows-specific user interface. This modification was relatively simple.

2. METRo was developed for Linux platforms. The METRo authors have indicated that modification of their code for Windows is not difficult. This would likely need to be done by the METRo developers and not end users.

B. Language(s)

1. FASST is written in FORTRAN. A FORTRAN-90 compiler is required. This may be an additional cost for any end user. The compiler cannot be included in the MDSS release.

2. METRo has modules written in C++, Python, and FORTRAN-77. It requires standard C++ and FORTRAN libraries. It also requires an external, publicly available library to interface between the various modules. Some of the internals would need to be redeveloped to interface with the Windows version of this library.

C. Code Stability

1. FASST is a research grade model that is being continually upgraded for use by the U.S. military. Its envisioned use is extremely broad in scope with users at various bases around the world being able to initiate runs. That being said, the source code does not yet appear to be stable at this time. CRREL does not have a history of using revision control on their software. This seems to still be the case as the version of FASST that was downloaded as part of this evaluation needed to be updated several times by CRREL with “improved” versions of certain modules. The version of FASST that was ultimately evaluated appears stable, but it has only been tested on a few cases. If any problems appear in the future, there may be a lengthy process involved in getting another stable version.

2. METRo is an operational model used by Environment Canada, and it has been designed specifically to forecast local pavement temperatures and road conditions. The METRo web site (http://home.gna.org/metro/) describes any model changes/updates and has a Frequently Asked Questions (FAQ) section for new
users. NCAR did not have any difficulty running the downloaded version of METRo.

D. Installation and Documentation

1. FASST was reasonably easy to download and install. Minor modifications were required to run the software under Linux. The documentation was much better than its predecessor, SNTHERM. The experience and knowledge NCAR has acquired over the last few years regarding the installation, implementation, execution, and structure of SNTHERM likely made this process simpler for FASST. In developing the input file containing the meteorological data, it became clear that the way FASST uses the data is a bit ambiguous. FASST is designed to work on an incomplete meteorological data set. However, the meteorological data required to generate the necessary weather inputs are not well documented. For example, FASST will “derive” solar radiation data if only forecasted cloud coverage and solar zenith and azimuth data are provided. However, if the forecast radiation data are provided, the cloud data are ignored. But, if the solar zenith angle is not provided or set to zero, it is assumed that the sun is below the horizon irrespective of the time of day.

2. METRo was easy to download and install, and the online documentation appeared to be complete. A junior level software engineer had only minor difficulties in accomplishing this work. The documentation is also available in a wiki (http://documentation.wikia.com/wiki/METRo), which is a collaborative online document that is continuously updated by developers and users. As more users use METRo, the wiki could potentially be updated with helpful information and troubleshooting tips.

E. Support and Responsiveness

1. The developers of FASST were helpful in spite of other commitments at CRREL. The FASST development team helped to identify modules that required upgrades in the release provided to NCAR. On occasion, their response was delayed due to prior obligations and time constraints at CRREL.

2. The METRo development team was very responsive. On one occasion, the model was not producing road temperature output. The developers analyzed the problem and found that the subsurface configuration used to initialize METRo contained a layer that was too thin for METRo. They modified the code to output a message indicating the problem and updated the documentation to describe the layer thickness limits. The developers seemed open to feedback and eager to help with any problems.
F. Model Initialization

1. FASST requires weather forecast data, a layer structure description, and an optional initial subsurface temperature profile for its initialization. The configuration files are in text formats that are well documented. As described above, the weather data required to produce road temperature forecasts are minimal; however, additional weather data will potentially result in an improved forecast. The layer structure description allows for simple choices of standard material types such as concrete and asphalt, but it also allows sophisticated users to create their own materials with properties that are more suited to their environment. The complete initial subsurface profile is not known at the initialization time. If the forecast site is an Environmental Sensing Station (ESS), the surface and subsurface temperatures may be available, and this information can be used to provide an initial subsurface temperature profile in the configuration. The MDSS has used the forecast subsurface temperatures from previous runs for this initialization (when using SNTHERM). The initial profile is modified slightly to match recent observations. This process should work similarly for FASST. This process works for both observing and non-observing forecast sites.

2. METRo’s configuration files are in the industry standard XML format. METRo also requires weather forecast data and a layer structure description. Instead of an initial subsurface profile, METRo requires an observational history of the surface and, if available, subsurface observations. Using this history, METRo develops its own estimate of the current subsurface temperature profile. At least a 3 hour history is required and 12 hours is preferred. Generating this history will present challenges at non-observing sites. A pseudo-history will need to be created in a way similar to how the pseudo-subsurface profile is currently generated for SNTHERM in the MDSS. METRo is more specific in its weather inputs. It does not accept redundant information like FASST does (for example, cloud cover and insolation). Currently, it does not use solar radiation data. Instead, it uses cloud cover in octants. Experience with SNTHERM showed that providing forecast radiation data, instead of cloud cover data improved model performance. The METRo developers indicated that METRo could be upgraded to accept forecast radiation data directly.

G. Computational Speed

1. FASST takes less than 0.2 seconds to generate a 48 hour road temperature and snow depth forecast for one site.

2. METRo takes approximately 2 seconds to generate a 48 hour forecast initialized with a 12 hour observational history for one site.

The difference in wall clock time for the two models is probably due in part to the languages each uses. FASST is all compiled FORTRAN code. METRo uses C++ and FORTRAN (compiled) as well as Python (interpreted). Interpreted languages are slower. Also, FASST uses simple CRREL-defined file formats whereas METRo uses
the industry standard XML format. The parsing of XML input files and/or writing the XML output files takes a significant amount of the processing time. The METRo developers estimate that the XML I/O takes approximately 90% of the run time. Using the industry standard, XML, keeps METRo from being comparable to FASST in terms of run time, as it takes roughly 10 times longer to generate a 48 hour forecast using METRo.

The timing may be an issue for end users that support large numbers of forecast sites. For example, for the Colorado MDSS, which supports E-470 and the City of Denver, there are 20 forecast sites. To run the roadway and bridge forecasts, with the initialization, no treatment, current treatment, and recommended treatment options, METRo would require over 6 minutes of wall clock time. In addition, the current MDSS configuration requires that the energy balance model be rerun after each recommended treatment so that the appropriate subsequent treatment can be determined; therefore, during a significant event, the model execution may occur tens of times for one forecast cycle at one individual site, adding additional processing time. This does not scale well for end users supporting statewide or multi-state operations. However, this issue could be easily resolved by moving away from the use of XML as an input/output mechanism for METRo.

3. Performance

Several case studies were performed to compare road temperature predictions from FASST, SNThERM, and METRo to observed road temperatures for an ESS (6th Parkway site) along E-470, east of the Denver METRo area. The 6th Parkway site was selected because it is the only RWIS site that reports insolation. Appendix A provides a map of the E-470 and Northwest Parkway toll roads, along with the location of the 6th Parkway ESS. An annotated photograph displaying the location of the ESS tower and road temperature sensor can be found in Appendix B. The elevation of this ESS is approximately 5,535 feet. It supplies atmospheric data (e.g. air temperature, relative humidity, wind speed, and wind direction) and pavement temperature data (surface and subsurface).

For each case, two types of analyses were completed: one in which road temperature predictions were generated using forecast atmospheric data and another in which predictions were generated using observations (perfect prognosis [perfprog] approach). The forecast data were derived from the MDSS road weather forecast system (RWFS). For the perfprog analysis, the observation data, including insolation measurements, are primarily from the Vaisala ESS; however, since the ESS does not report precipitation or cloud cover, precipitation observations from a GEONOR gauge and cloud cover from the Automated Surface Observing System (ASOS) at Denver International Airport (DIA) are used. Although these platforms provided the closest precipitation and cloud cover data, it should be noted that they are approximately 9 statute miles away from the 6th Parkway site; therefore, these data are not always representative of the environmental conditions at the 6th Parkway ESS site. Six cases that exhibited a variety of weather were examined:
Hot, Clear, No Precipitation  12 July 2006
Warm, Clear (Day1), Cloudy (Day 2)  08 November 2006
Warm Moderate Rain  07 July 2006
Cold Light Rain  11 November 2005
Light Snow (~2 inches) / Arctic Outbreak  15 February 2006
Moderate Snow (~ 5-6 inches)  28 November 2006

The forecast figures show 48 hour forecasts generated at 12Z (0500 MST / 0600 MDT) and corresponding observations from the ESS road sensor. The x-axis displays lead time (hours out) from 12Z on the day indicated. For the forecast driven precipitation cases, times at which precipitation was forecasted and times when precipitation was observed are indicated on the plots by the green and cyan circles, respectively. For the perfprog analyses, only observed precipitation is indicated.

Although the models are examined during light snow and moderate snow events, care should be exercised when attempting to draw definitive conclusions regarding model performance under these conditions. Forecasted pavement temperatures are plotted against actual observations in the perfprog charts, but it is unclear what, if any, winter maintenance activities took place during each snow event. The use of chemicals and plowing to control ice and snow will have an effect on the observed pavement temperatures. The models do not “know” what actions have been taken to treat the section of E-470 from which the pavement temperature observations are derived; therefore, the forecast may not conform to the observed values. However, it is reasonable to compare the models to one another during these events in an effort to investigate characteristics unique to each model.

A. Clear Cases

12 July 2006

The 12 July 2006 event was characterized by mostly clear and hot conditions, with air temperatures in the mid to upper 90s. For the RWFS forecast driven analysis (Figure 1), SNTHERM and FASST are closer to the peak road temperature on the first day (lead times 6-12); however, none of the models pick up on the sawtooth pattern in observed road temperatures associated with passing clouds on the first day, which can be attributed to a clear weather forecast. On the second day, all three models do a respectable job, but METRo most accurately predicts the peak in road temperatures (30 – 36 hours). All three model forecasts exhibit a warm bias during the morning hours on the first and second day. During the evenings, SNTHERM does well to capture cooling under forecasted clear conditions, while FASST and METRo forecasts indicate cooling a bit too soon. During the overnight hours, the models are fairly similar, but the RWFS driven METRo forecast indicates pavement temperatures that are slightly too cool.
Figure 2 shows the perfprog predictions for the 12 July case. By using the solar radiation directly, SNTHERM and FASST are able to forecast the drop in observed road temperatures during the middle of the first day; however, the dip in pavement temperature is exaggerated in both models. METRo is too warm during the first day, which may be an artifact of having to use observed cloud cover from a site not co-located with the pavement temperature verification site. On the second day, METRo does the best job predicting the peak in road temperature, while SNTHERM and FASST under-predict the peak. METRo continues to show a slight warm and cold bias in the morning and evening, respectively. Much like METRo, FASST also exhibits a cold bias during the evening periods. While all the models generate comparable nighttime temperature forecasts, SNTHERM shows the most skill in this case.

![Figure 1](image)

**Figure 1.** FASST (red line), METRo (green line), and SNTHERM (blue line) road temperature forecasts based on RWFS output for 12Z on 12 July 2006. Observed road temperature is indicated by the black line.
Figure 2. As in Figure 1, except perfect prognosis generated road temperature forecasts for 12Z on 12 July 2006.

8 November 2006

A record high temperature of 80°F occurred on 8 November 2006 followed by a weak cold front on 9 November. Figure 3 shows that for the forecast driven predictions on day 1, METRo is the closest to the observed road temperatures. FASST and SNTHERM both under-predict the peak in road temperature, with FASST being about 5°C too cold. All three models are slightly out of phase with the peak in road temperatures on the first day. On day 2, all three models grossly over-predict the road temperatures as a result of an inaccurate weather forecast.

The perfprog analysis provides additional detail regarding the models’ performance given an optimal forecast. Figure 4 shows that METRo closely matches the observations on day 1 and is by far the best forecast, as it not only captures the peak heating, but it does well to forecast the increase and decrease in pavement temperature during the morning and afternoon, respectively. SNTHERM and FASST both under-predict the road temperatures in the afternoon (lead times 6-15), with FASST being the worst of the two.

On day 2, METRo has the better forecast overall, although differences in cloud cover used by METRo and what was observed at the Vaisala site are apparent. SNTHERM and FASST again under-predict the road temperatures on the second day. METRo and FASST do reasonably well predicting the pavement temperatures on the first night, but they are
both too warm on the second night, while SNTHERM generally has a cold bias on both nights (lead times 18-27 and 39-48).

Figure 3. As in Figure 1, except for 8 November 2006.

Figure 4. As in Figure 2, except for 8 November 2006.
B. Rain Cases

11 November 2005

The 11 November 2005 case was characterized by partly cloudy conditions on the first and second day and light rain overnight. For the forecast driven analysis, Figure 5 shows that METRo’s forecast is considerably better than SNTHERM and FASST during the middle of the first day (lead times 3-12). This can be attributed to different ways in which each model calculates surface energy. METRo uses cloud cover to derive incident solar radiation whereas SNTHERM and FASST use solar radiation directly. Cloud cover forecasts from the RWFS are not directed related to the solar radiation forecasts (they come from different sources). Thus, using cloud cover to derive solar radiation can lead to a much different road temperature forecast than those based on predicted radiation values. This is clearly the case here where on day 1 lower solar radiation values associated with the forecasted rain results in lower road temperature predictions from SNTHERM and FASST. The cloud cover forecast is more accurate and results in a better road temperature forecast from METRo. On day 2 the cloud cover and solar radiation forecasts are better correlated and thus the road temperature predictions between the three models are similar.

Figure 5 shows that during the evening and overnight hours, the forecasts from SNTHERM and METRo are very similar. Both models over-predict the temperatures during the night, with SNTHERM providing a slightly better nighttime forecast. During the same period, FASST performance is not nearly as good as SNTHERM and METRo, as it exhibits even greater difficulty forecasting the nighttime cooling.

On the second day, SNTHERM and FASST do much better predicting the peak heating, with FASST doing the best out of all three models. However, the superior results from FASST are likely because it over-forecasted the lows during the previous night. All of the models show very similar characteristics during the evening and night of the second day when compared to the previous evening and night. SNTHERM does the best, followed by METRo and then FASST.

Using a perfprog approach (Figure 6), SNTHERM and FASST are able to pick up on the subtle changes in road temperature using the observed solar radiation values whereas METRo does not (day 1). METRo uses observed cloud cover from the ASOS located at DIA, which is likely different than the cloud cover observed at the Vaisala site. Due to the difference in cloud cover between the two sites, METRo has difficulty picking up on brief reduction in road temperature associated with passing clouds at the Vaisala site for lead times 6-9.

During the afternoon and evening hours of the first day, both METRo and SNTHERM do an excellent job of predicting the decrease in pavement temperature, while FASST begins to exhibit cooling slightly too early. The onset of precipitation results in a notable drop in pavement temperature (lead time of 15 hours), but the models do not immediately respond to
this drop. Overnight (lead times 16-27), SNTHERM and METRo do begin forecasting cooler road temperatures associated with the rain whereas FASST does not. FASST is too warm at night, and this is especially evident on the second night (lead times 39-48).

On day 2, the road temperature predictions from the three models are again very similar, with SNTHERM and METRo performing slightly better than FASST. Although FASST’s peak temperature is closer to reality, it warms too soon during the morning and cools too soon during the afternoon. As previously mentioned, the forecasted temperatures from FASST are considerably higher than the observed temperatures during the second overnight period. SNTHERM’s afternoon forecast is similar to FASST, but does a good job predicting the overnight temperatures on the second day. METRo’s forecast is comparable to SNTHERM; however, its afternoon forecasted temperatures are a bit more in line with the observed conditions. The overnight temperatures from METRo are slightly too cool on the second night.

Figure 5. As in Figure 1, except for 11 November 2005.
7 July 2006

On 7 July 2006, a summer cold front moved across the Colorado Front Range producing a prolonged period of moderate rain, dropping temperatures from the 80s into the 60s. Figure 7 indicates that for the forecast driven road temperatures, SNTHERM and FASST respond well to the reduction in solar insolation associated with the predicted onset of rain (lead times 6-15). The METRo forecast on the first day is an artifact of a clear cloud cover forecasts, and although it is closer to the peak road temperature compared to SNTHERM and FASST, it does not respond to the predicted rain. All three models are too warm overnight (lead times 15-24), with FASST being the warmest and METRo being the closest to observed values. By the morning of the second day (lead time 24), METRo is the closest to the observed road temperatures. All three models are out of phase with the peak in observed road temperatures on the second day (lead times 24-39), and this can be attributed to differences between the weather forecasts and the observed weather conditions.

For the perprog analysis, Figure 8 shows that METRo has the best overall road temperature forecast on the first day. SNTHERM and FASST under-predict the peak in road temperatures (on the first day) using the observed radiation values. These models also show a notch pattern during the morning of the first day, which is not seen in the observed values. Overnight, METRo’s forecast is the best, with SNTHERM a close second; FASST remains too warm. On the second day the differences between using observed cloud cover to derive solar radiation versus using observed radiation is apparent. SNTHERM does the best job of picking up on the sawtooth pattern observed in road temperatures, which is associated with
the intermittent rain. Although METRo does not pick up on the details, it outperforms FASST and does well predicting the decrease in road temperature during the late afternoon on the second day.

![Figure 7. As in Figure 1, except for 7 July 2006.](image-url)
C. Snow Cases

15 February 2006

On 16 February 2006, a strong Arctic cold front pushed across the Colorado plains bringing with it light snow and cold temperatures. The road temperature forecasts for this event start at 12Z on 15 February. The front moves through after the day 1 forecast at approximately 05Z on 16 February (lead time 16). The forecast driven predictions on day 1 are generally good. All three models are within 5°C of the observed peak in road temperature (Figure 9), with FASST performing the best during this period, followed closely by METRo and then SNHERM.

All of the models do well to forecast the increase in pavement temperatures on day 1, but both SNHERM and FASST start out a few degrees too cold. The forecast driven predictions of pavement temperature do not do as well during the afternoon and early evening hours, as all of the forecasts delay the cooling. Overnight (lead times 15-25), all three models are too warm. SNHERM is the closest to the observed temperatures during the majority of the night, but METRo does better at capturing the low temperature.

On day 2, there are big discrepancies between the model predictions. METRo has by far the best forecast, tracking fairly close to the observed road temperatures during the
middle of the day (lead times 30-39). FASST is too warm, predicting a peak in road temperature that is 10°C above what is observed. Unlike SNTHERM and METRo, SNTHERM road temperatures are clearly dampened on the second day and this is due to the model’s build up of snow on the road. On the second night (lead times 39-48), METRo and especially FASST are too warm, and this can be attributed to discrepancies between the weather forecasts and what was actually observed.

For the perfprog analysis (Figure 10), all three models under-predict road temperatures on the first day. Unlike what was observed in the forecast driven cases, the METRo forecast is closer to the high temperature in terms of peak heating, followed closely by FASST and SNTHERM. It appears that the air temperature may be limiting the temperatures predicted by each model. The utilization of insolation data allows both SNTHERM and FASST to pick up on the fact that the morning temperature profile flattens for about two hours; however, both models indicate a decrease in pavement temperature, which is not supported in the observations. All three models predicted decreasing pavement temperature too early during the afternoon of the first day.

Overnight, the METRo forecast closely matches the observations and even picks up on the slight increase in road temperature during a break in the snow (lead times 23-25). SNTHERM and FASST are too warm during the coldest part of the night; however, FASST does show some response to the break in snowfall. Again, it is evident that SNTHERM road temperatures are dampened due to the model’s build up of snow on the road, as there is very little variation in pavement temperature after the snow begins.

On the second day, FASST tracks well with the observed road temperatures during the early portion of the day, but it predicts a substantial decrease in temperature during the middle part of the day (lead times 32-33). This decrease can be attributed to a decrease in the observed solar radiation values used to drive the model. Given the observed pavement temperatures, it is very likely that there is little snow left over on the road on day 2. METRo road temperatures are well below the observed values. This is possibly due to the influence of the very cold air temperatures and/or discrepancies between the actual cloud cover at the Vaisala site and that measured at the DIA ASOS site. The pavement temperature profile from SNTHERM is basically flat during the day, which is quite similar to the forecast driven output (Figure 9).

During the night of the second day (lead times 39-48), SNTHERM and FASST are slightly warmer than the observed values, while METRo’s temperatures are slightly colder. However, METRo’s profile is very similar to the observed conditions, and it does well to forecast the lowest temperature during this period.
Figure 9. As in Figure 1, except for 15 February 2006.

Figure 10. As in Figure 2, except for 15 February 2006.
28 November 2006

The 28 November 2006 case is a prolonged moderate snow event with relatively warm air temperatures initially followed by much colder temperatures on 29 November. The event resulted in approximately 5 to 6 inches of snow at the 6th Parkway Vaisala site. Snow started at 5 p.m. on 28 November (lead time 12). Figure 11 shows that for the forecast driven output, all three models do well predicting road temperatures on the first day. Minor differences include the fact that FASST does a slightly better job of forecasting the increase in pavement temperatures during the first few hours of the day, but METRo’s predictions are superior to FASST and SNThERM during the afternoon.

After the predicted onset of snow (lead time 8), FASST is too warm through the rest of the forecast. The warm bias may be tied to the idea that FASST does not build up enough snow on the road. Initially SNThERM responds well to the onset of snow and the forecast tracks well with the observations, but as the model builds up snow on the road, temperatures become dampened and do not respond on the second day. METRo has the best overall forecast with just a slight cold bias on day 2 (lead times 27-36) and a slight warm bias through the second night (lead times 36-48). These biases may result from differences between the predicted cloud cover and precipitation and the actual observations.

The perfprog road temperature predictions for the 28 November case (Figure 12) show similar results to the forecast driven predictions. During day 1, all three models under-predict the peak in observed road temperatures (lead times 6-9). METRo once again does well to forecast the decrease in temperature during the afternoon, while the decrease in pavement temperature noted by SNThERM and FASST occurs too early. After the onset of snow (lead time 12) METRo has the best forecast, closely matching the observations throughout the evening and overnight period. During the night FASST predicts colder temperatures compared to the actual observations, while the SNThERM forecast remains too warm.

On the second day, METRo under-forecasts the increase in pavement temperature that occurs after sunrise, but its forecast remains substantially better than FASST and SNThERM. Although FASST does forecast an increase in pavement temperature, its temperatures are much warmer than the observed values, and it continues to exhibit a very warm bias throughout the remainder of the forecast period. SNThERM’s forecast is dampened due to the model’s build up of snow on the road; as a result, the forecast is rather poor.
Figure 11. As in Figure 1, except for 28 November 2006.

Figure 12. As in Figure 2, except for 28 November 2006.
4. Summary and Conclusions

In an effort to determine and recommend a potential replacement road temperature model for SNTHERM, which is no longer being supported by CRREL, a broad assessment of FASST and METRo has been conducted. The results of this assessment have been included herein, and they take into account elements such as forecast performance, code stability, support, efficiency, and ease of use. In terms of overall forecast performance, METRo provided the best forecast for the cases that were examined, which included a wide range of weather conditions. Although FASST did exhibit good performance under certain conditions, its overall performance was not as good as METRo or SNTHERM.

METRo was also very easy to obtain and install, while FASST required multiple interactions with the developers before a stable version could be installed that provided good results. Although the developers of FASST were open to helping with the model set up, other commitments sometimes delayed their response. METRo developers were very responsive to requests they received during this exercise. They appeared to be very open to feedback and eager to help with any problems.

One of the primary weaknesses of the METRo model is the amount of time it takes to run the model. While FASST and SNTHERM take less than 0.2 seconds to generate a 48 hour road temperature and snow depth forecast for one site, METRo takes roughly 2.0 seconds. FASST and SNTHERM use simple CRREL-defined file formats whereas METRo uses the industry standard XML format. It is estimated that the parsing of XML input files and/or writing the XML output files takes roughly 90% of the processing time. METRo’s inefficient speed may pose some difficulty for users wishing to forecast at a large number of sites; however, this problem could be rectified by creating an alternative method to handle METRo’s input/output process.

Despite the fact that METRo takes considerably longer to generate a 48 hour forecast than FASST and SNTHERM, it possesses many traits that make it attractive for use in the MDSS, as well as other decision support systems. Not only has METRo performed well under a number of conditions, but experience has also shown that it is extremely easy to acquire, install and use, even for novice users. Moreover, the support provided by the developers, along with an expanding community of end users, will ensure that problems or issues that do arise can be addressed and corrected in a timely manner. As a result of these factors, it is recommended that METRo be used in future releases of the MDSS and in the development of other decision support systems targeting roadway maintenance and operations.
5. References


6. Appendices

Appendix A. Map of E-470 and Northwest Parkway. Location of the 6th Parkway ESS denoted by the red arrow.
Appendix B. Photograph of Environmental Sensor Station at 6th Parkway. Tower location and road temperature sensor indicated by black arrows.