Effects of Model Data on the Validity of a Frost-Prediction Model

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ABSTRACT

The author investigates the impact of using MM5 model data for input in a frost model that previously used RWIS observations for input. Model performance was studied and found to have improved slightly through incorporating a new LSM, however, model errors still exist. The formation of frost is very sensitive to pavement temperature. MM5 surface temperature and actual pavement temperature were found to be different enough to warrant the use of a separate model designed to calculate pavement temperatures for better frost model accuracy. This paper suggests a possible way a new pavement surface temperature model can be built using MM5 forecasted values.

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1. Introduction

Frost on roadways and bridges creates a potentially dangerous situation for motorists. Roadway maintenance workers apply salt and other chemical solutions to suppress frost, but this is costly to taxpayers, car owners and the environment. Salt causes pavement and vehicle corrosion and pollutes soil and waterways. On a yearly basis, the cost of corrosion of vehicles is estimated to be in the millions of dollars (Shao and Lister, 1996). If de-icing techniques were applied only when needed, it would save unnecessary chemical and vehicle maintenance costs and environmental pollution, while maintaining the same level of safety of our roads. A frost prediction model was designed to improve the ability to predict frost so road crews can know in advance when anti-icing solutions are needed and when they are not.

The frost model used in this study was created by David Knollhoff as part of his graduate research on pavement temperatures and frost formation on roadways and bridges (Knollhoff, 2001). It is a Fortran 90 program that calculates the accumulated depth of frost on a roadway given two-meter air temperature, dewpoint temperature, wind speed, and pavement surface temperature, as collected by the Road Weather Information System (RWIS) (Knollhoff, 2001). This model is currently being used to forecast the depth of frost. The model itself has not been changed; instead the frost model receives forecasted values from the Fifth Generation Penn State/NCAR Mesoscale Model (MM5) rather than from observations. Since we are now supplying input values from a model, it is important that we understand how this switch will impact the frost prediction.

The MM5 that was studied has been run in the Department of Agronomy’s Earth Science Simulation Lab at Iowa State University since August 2001. It forecasts for the city of Ames, Iowa, with a 20 km resolution grid. This model outputs two-meter air temperature, dewpoint temperature, wind speed, and surface (skin) temperature for the grid terrain once every 6 minutes for 48 forecast hours. The model outputs forecasts twice a day; one at 0 UTC and one at 12 UTC. These values are fed into the frost model that outputs the accumulated frost for the forecasted time. No model is perfect so it is inevitable that the MM5 will be introducing error into the frost-depth calculations. Furthermore, the surface temperature calculated by the MM5 is not the same as bridge surface temperature. The purpose of this project has two objectives; to study the MM5's performance to understand the impacts its values would have on the output of the frost model, and to investigate whether MM5 surface temperature would be an acceptable approximation for bridge surface temperature.

2. Procedure and results

a. Determining model error

For this project, only the values relevant to the frost model input were studied. The two-meter air temperature, dewpoint, windspeed, and skin temperatures were compared with observations taken at the Ames airport and by hand in the ISU cross country field for the period between 18 September, 2001 and 14 November, 2001. The Ames airport does not take skin temperature measurements, so they were taken by hand. In order to minimize errors due to topography, a specific location in the middle of a flat, grassy part of the ISU cross-country field was chosen as the observation site. The model values for each parameter were compared against the observed values to find biases, average error, and standard deviation. These comparisons help illustrate the strengths and weaknesses of the MM5, and how we can expect it to affect the frost model. The 0 UTC and 12 UTC runs were analyzed separately to investigate the trends characteristic to those runs. The 0 UTC run had warm biases in both two-meter air temperature and dewpoint temperature, as well as a fast bias in windspeed. The 12 UTC runs had only very slight biases in air and dewpoint temperature, but it also had a fast bias in its windspeed. Though nearly unbiased in temperature and dewpoint, it had an average error similar to the 0 UTC runs (Table 1).

0 UTC	Temperature (°F)	Dewpoint (°F)	Speed (kts)
Bias	1.75	1.52	4.19
Average error	3.57	3.83	4.95
Standard dev.	4.29	4.74	4.30
Max error	13.32	12.78	16.00
Min error	-10.98	-19.98	-9.00

12 UTC	Temperature (°F)	Dewpoint (°F)	Speed (kts)
Bias	-0.04	0.38	3.88
Average error	3.23	3.24	4.83
Standard dev.	4.13	4.23	4.45
Max error	12.42	13.50	18.00
Min error	-13.14	-13.50	-9.00

Table 1: 0 UTC and 12 UTC run performance with original settings from 20 September, 2001 to 24 October, 2001

The MM5's performance for its surface temperatures was more difficult to study since there was no data available at regular intervals. In the case of the MM5 air temperature, dewpoint and windspeed, there were hourly observations available for comparison. The surface temperature observations were usually taken once or twice a day. These observations could test the model's performance at one instant, but were insufficient to detect problems with diurnal cooling/heating rates or timing. For MM5 surface temperature, both the 0 UTC and the 12 UTC runs had a warm bias. The 0 UTC run bias was nearly twice that of the 12 UTC run. Both runs averaged nearly five degrees off from actual (Table 2).

Old LSM	0 UTC	12 UTC
Bias (°F)	4.51	2.62
average error (°F)	5.47	4.59
Standard dev. (°F)	5.19	5.21
Max error (°F)	14.32	12.17
min error (°F)	-7.57	-9.95

Table 2: Surface temperature error with old LSM.

In early November, the Oregon State University Land Surface Model (OSULSM) was adopted as the surface physics scheme for this model. The OSULSM aids the MM5 in interpreting surface forcing. The original land surface model (LSM) could not reflect recent changes due to precipitation, snow cover, vegetation evapotranspiration, or water runoff (Chen and Dudhia, 2001). The OSULSM has been found to reasonably represent diurnal variation of sensible heat fluxes and skin temperature, as well as the seasonal and diurnal changes in evaporation and soil moisture (Chen and Dudhia, 2001). The model was allowed several days to adjust to the new land surface model prior to analysis. With the LSM change, the dewpoint temperatures improved in both runs but there was little improvement in temperature or wind speed. The 12 UTC temperatures average error increased for the period studied (Table 3).

The MM5's skin temperature performance between the 0 and 12 UTC runs was very different. The 0 UTC run almost always overestimated the surface temperature

Table 3: 0 UTC and 12 UTC run performance (a) with OSU LSM from 06 November 2001 to 19 November 2001 and (b) the difference between the OSULSM (New) runs and the original (Old) runs.

a 0 UTC run	Temperature (°F)	Dewpoint (°F)	Speed (kts)	12 UTC run	Temperature (°F)	Dewpoint (°F)	Speed (kts)
Bias	-0.08	1.36	4.58	Bias	-3.41	-0.20	3.86
Average error	3.16	2.86	5.36	Average error	4.18	2.65	4.99
Standard dev.	3.81	3.65	4.38	Standard dev.	3.95	3.43	4.60
Max error	10.98	10.44	18.00	Max error	7.38	7.02	18.00
Min error	-10.44	-10.98	-7.00	Min error	-15.12	-12.42	-8.00

b 0 UTC difference (New - Old)	Temperature (°F)	Dewpoint (°F)	Speed (kts)	12 UTC difference (New – Old)	Temperature (°F)	Dewpoint (°F)	Speed (kts)
Bias	-1.83	-0.16	0.39	Bias	-3.37	-0.58	-0.02
Average error	-0.41	-0.97	0.41	Average error	0.96	-0.60	0.16
Standard dev.	-0.48	-1.09	0.08	Standard dev.	-0.18	-0.80	0.15
Max error	-2.34	-2.34	2.00	Max error	-5.04	-6.48	0.00
Min error	0.54	9.00	2.00	Min error	-1.98	1.08	1.00