<u>Project Title:</u> Environmental Impacts on the Performance of Pavement Foundation Layers-Phase 1 (Contract 1035211)

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SUMMARY REPORT for Q1 for 2020

The two main areas of effort completed over this reporting period including completion of a literature review of modeling methods used to evaluate soil performance characteristics, and second, additional progress towards the development and validation of models to predict freeze-thaw performance. We summarize our progress below.

Literature review: We have conducted a literature review of recent research in this area. In recent years there have been several studies on related topics. These are focused on predicting soil temperatures at different depths, at different times of the year; most focus on predicting the average monthly surface temperatures. None of the papers focus on the prediction of daily or hourly temperature fluctuation and/or freeze-thaw behavior. Among the current related studies published, linear and multiple regression and the neural networks are the most commonly applied models for this type of study. Building on our understand of these recent research efforts, we have concluded that the results of these studies and the methods used can be helpful in informing our modeling efforts herein.

Model development: Based on the findings from the literature review, we continue to work on the development of a model to predict soil temperatures at different depth, at sub-hourly timesteps and, ultimately, to evaluate the number of freeze-thaw cycles at each of these depths.

In our recent modeling efforts, the temperature at different soil depths is studied individually, rather than as a function of the temperature and/or conditions at other soil depths. Currently we are considering a range of inputs as predictor variables, including air temperature (TA), wind speed (WS), relative humidity (RH) and precipitation (Rain), day of the year' (DY), hour of the year (HY) and timestep of day (TD). For 'day of year', this represents a value between 1 to 365, 'hour of year' varies from 1 to 8760 which represents the hour of year. To predict the soil temperature at 15 minute level increments, the 'timestep of day' variable is considered, where it represents the particular timestep of a given day. This variable can be used to predict the daily variation in soil surface temperature. After evaluating the correlation coefficients of the variables, forward stepwise regression was used to identify the most significant variables to predict the temperatures at different depth of soil. The result of the stepwise regression is shown in Table 1.

Table 1: Parameter selection from forward stepwise regression

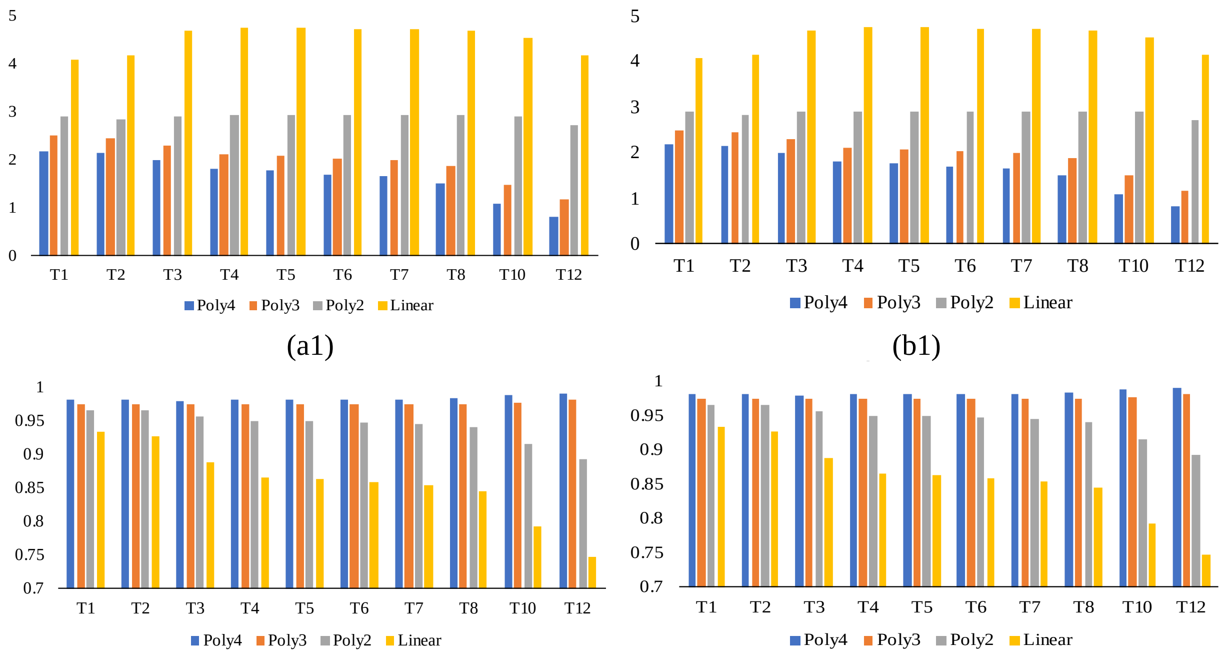
Soil temperature	Depth (in)	Selected variables
T1	2.8	TA, RH, WS, TD, DY, Rain
T2	3.8	TA, RH, WS, TD, DY, Rain
T3	9.3	TA, WS, RH, TD
T4	14.8	TA, RH, WS, TD, DY, Rain
T5	15.8	TA, RH, WS, TD, DY, Rain
T6	18.3	TA, RH, WS, TD, DY, Rain
T7	19.3	TA, RH, WS, TD, HY, Rain
T8	23.8	TA, RH, WS, TD, DY, Rain
T10	47.8	TA, RH, WS, TD, DY, Rain
T12	71.8	TA, RH, WS, TD, DY, Rain

As the Table shows, the parameters of importance are consistent for all the temperatures are generally consistent, with a few exceptions. As such, to use a uniform data input for all depths, air temperature, relative humidity, wind speed, precipitation, day of year and timestep of day are selected as the parameters based on the result obtained from the stepwise regression. Linear and non-linear regression are then used to predict the soil temperatures. A maximum power of 2, 3 and 4 for each of the variables, with interactions terms included, are used for nonlinear regression. As the thermal radiation is proportional to fourth power of temperature, a maximum of the fourth power polynomial is selected for this study. The data for the year

2018 is used to train the model whereas the data from January 2019 to May 2019 is used to test the performance of the model. Root sum error (RSE) and the adjusted R^2 value are used to evaluate the performance of the model. The result of the training and testing error is shown in Figure 1.

As shown in Figure 1, the non-linear regression models perform significantly better than the linear regression models for all depths. RSE values using linear regression are also significantly higher compared to the non-linear regression models. Similarly, adjusted R^2 values of soil temperatures are much lower for linear regression models compared to the non-linear regression models. The adjusted R^2 values also decrease significantly with the depth of soil for linear regression analysis, specifically it reduces from approximately 0.93 to 0.73 with the increase in depth.

In the figure, Poly2 represents the non-linear regression model results, with maximum order of 2. Poly3 and Poly4 are also defined in the same way. Increasing the order of the non-linear regression appears to improve the overall model performance. As shown from the RSE values, the error in prediction reduces significantly with the increase in order, and this difference is more significant for temperature predictions at greater depths. Therefore, as shown in Figure 1, fourth order polynomial regression performs significantly better compared to other modeling methods, and this model performance is consistent for different soil depths. Moving forward, the prediction of the number of freeze-thaw cycles will be evaluated for this model and will be compared with the actual levels obtained from the actual data.



(a1)

(b1)

(a2)

(b2)

Fig 1. Variation of (1) RSE value and (2) Adjusted R^2 values for (a) training and (b) testing data using linear and non-linear regression.