TECHBRIEF

The Long-Term Pavement Performance (LTPP) program is a large research project for the study of inservice pavements across North America. Its goal is to extend the life of highway pavements through various designs of new and rehabilitated pavement structures, using different materials and under different loads, environments, subgrade soil, and maintenance practices. LTPP was established under the Strategic Highway Research Program and is now managed by the Federal Highway Administration.

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Evaluation of LTPP Climatic Data for Use in Mechanistic-Empirical Pavement Design Guide (MEPDG) Calibration and Other Pavement Analysis

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This document is a technical summary of the Federal Highway Administration report, *Evaluation of LTPP Climatic Data for Use in Mechanistic-Empirical Pavement Design Guide (MEPDG) Calibration and Other Pavement Analysis* (FHWA-HRT-15-019).

Objective

This TechBrief describes evaluating the use of the Modern-Era Retrospective Analysis for Research and Applications (MERRA) product as an alternative climatic data source for the Mechanistic-Empirical Pavement Design Guide (MEPDG) and other transportation infrastructure applications. The research was conducted from 2011 to 2014.

Introduction

The analysis methodology developed in the AASHTO Mechanistic-Empirical Pavement Design Guide (MEPDG) and accompanying software, Pavement ME Design®, emphasize the influence of climate on pavement performance (*1*). The temperature and moisture analyses performed by the MEPDG's Enhanced Integrated Climate Model (EICM) require air temperature, wind speed, percent sunshine, relative humidity, and precipitation values at hourly time intervals over the entire design life of the project.

Weather history information required by the MEPDG is typically obtained from ground-based operating weather stations (OWS) located near the project site. The MEPDG software includes a climate database of approximately 800 OWS throughout the United States, most located at commercial airports. If needed, climate data from multiple nearby stations can be interpolated as a virtual weather station (VWS).

MERRA (*2*), developed by the National Aeronautics and Space Administration (NASA), is a physically based global climate reanalysis product that combines computed model fields (e.g., atmospheric temperatures) with ocean-, airborne-, and satellite-based observations that are distributed irregularly in space and time. MERRA employs Gridpoint Statistical Interpolation (GSI) system over a vast number of observations. More than four million physical observations are processed during a typical 6-hour data assimilation cycle. MERRA data are provided from 1979 to the present at an hourly temporal resolution and a horizontal spatial resolution of 0.5 degrees latitude by 0.67 degrees longitude (approximately 50 km by 65 km at midlatitudes) at multiple elevations in the atmosphere.

Research

Statistical comparisons between MERRA climate data and those from various conventional ground-based sources for several hundred locations and comparisons of MEPDG performance predictions using MEPDG OWS and MERRA climate data for twenty locations distributed across the contiguous United States were performed.

A variety of data sources were examined in this study. Ground-based climate data provided as part of the MEPDG serve as the standard input for flexible and rigid pavement simulations using the Pavement ME Design® software. Additional data sources employed for comparisons with the MEPDG climate files include the Quality Controlled Local Climatological Data (QCLCD), United States Climate Reference Network (USCRN), and NASA's MERRA.

Table 1 summarizes the meteorological data evaluated in this study, both from the MEDPG climate files and from the other climate data sources described in the subsequent sections.

MERRA is capable of providing all weather history inputs required by the MEPDG and other current infrastructure applications. Table 2 contains the MERRA data elements used to develop MEPDG weather history inputs.

MERRA contains additional data elements useful for enhancements of current infrastructure applications and/or for the support of future applications. A complete listing of all MERRA data elements can be found at http://gmao.gsfc.nasa.gov/products/documents/MERRA_File_Specification.pdf.

A major advantage of MERRA over ground-based climate data sources is the uniform spatial coverage. The ground-based Automated Surface Observation System (ASOS) stations that provide much of the current ground-based climate data are mostly located at airports and therefore clustered along the east and west coasts of the United States and around major population centers. Many MERRA grid cells contain no ASOS weather stations, and most MERRA grid cells that do contain ASOS weather stations usually contain no more than one.

Table 1. Variables employed from each measurement product for use during analysis.

Variable of Interest	QCLCD	MEPDG	USCRN	MERRA
Air Temperature	X	X	X	X
Dewpoint Temperature[1]				
Specific Humidity[1]	X	X	X	X
Wind Speed	X	X		X
Precipitation	X	X	X	X
Shortwave Radiation			X	X
Cloud Cover Fraction[2]		X		X
Sky Condition[3]	X			

X = Measurement / estimate is available at the majority of locations.
1 = Dewpoint temperature and specific humidity provide equivalent to humidity.
2 = Cloud cover fraction serves as a proxy for shortwave radiation.
3 = Sky condition serves as a proxy for cloud cover fraction, and hence, shortwave radiation.

Table 2. MERRA data elements used to develop MEPDG weather history inputs.

Element	Description	Units
CLDTOT	Total cloud fraction	fraction
PRECTOT	Precipitation flux incident upon the ground surface	kg H_2O m^2 s^{-1}
PS	Surface pressure at 2 meters above ground surface	Pa
QV2M	Specific humidity at 2 meters above ground surface	kg H_2O kg^{-1} air
SWGDN	Shortwave radiation incident upon the ground surface	W m^{-2}
SWTDN	Shortwave radiation incident at the top of atmosphere	W m^{-2}
T2M	Air temperature at 2 meters above ground surface	K
U2M	Eastward wind at 2 meters above ground surface	m s^{-1}
V2M	Northward wind at 2 meters above ground surface	m s^{-1}

Statistical analyses were conducted between the different data sources relative to USCRN (i.e., USCRN treated as the reference measurement) for the approximately 17-year period of 1 July 1996 through 1 September 2013. This time period corresponds to the approximate temporal overlap of all available data sources used in this study. The emphasis of the statistical evaluation was on temperatures, as prior studies have shown that pavement performance was most sensitive to these climate inputs (*3, 4*). Wind speed and cloud cover are the next most sensitive climate inputs; however, the USCRN data do not contain these data elements and consequently they could not be evaluated. Although the MEPDG in its current form assumes no infiltration of surface water into the pavement layers, precipitation data from the various climate data products were nevertheless compared.

For near-surface air temperature, the average bias across all 275 collocated datasets evaluated was 0.63 ^{o}C for QCLCD vs. USCRN and

1.40 ^{o}C for the MERRA vs. USCRN comparisons. The spread of the MERRA bias distribution is slightly broader than for the QCLCD data; the average root-mean-square (RMSE) values were 2.04 ^{o}C for the QCLCD vs. USCRN and 3.28 ^{o}C for the MERRA vs. USCRN comparisons. Overall, both the QCLCD and MERRA data were different and warmer than the USCRN reference values, with the MERRA data being slightly more warm and variable.

Analyses were conducted for hourly precipitation rates between collocated USCRN, QCLCD, and MERRA stations. Both the QCLCD and MERRA data closely agree with USCRN precipitation measurements, but MERRA has 50 percent less average bias than does QCLCD (0.02 mm/hr vs. -0.03 mm/hr). Further, numerous QCLCD stations contain significant negative bias relative to USCRN, which is consistent with rain gauge "under catch" that is a known and pervasive problem with point-scale rain gauges. The RMSE is also slightly lower in the MERRA estimates (0.81 mm/hr vs. 0.90 mm/hr for QCLCD).

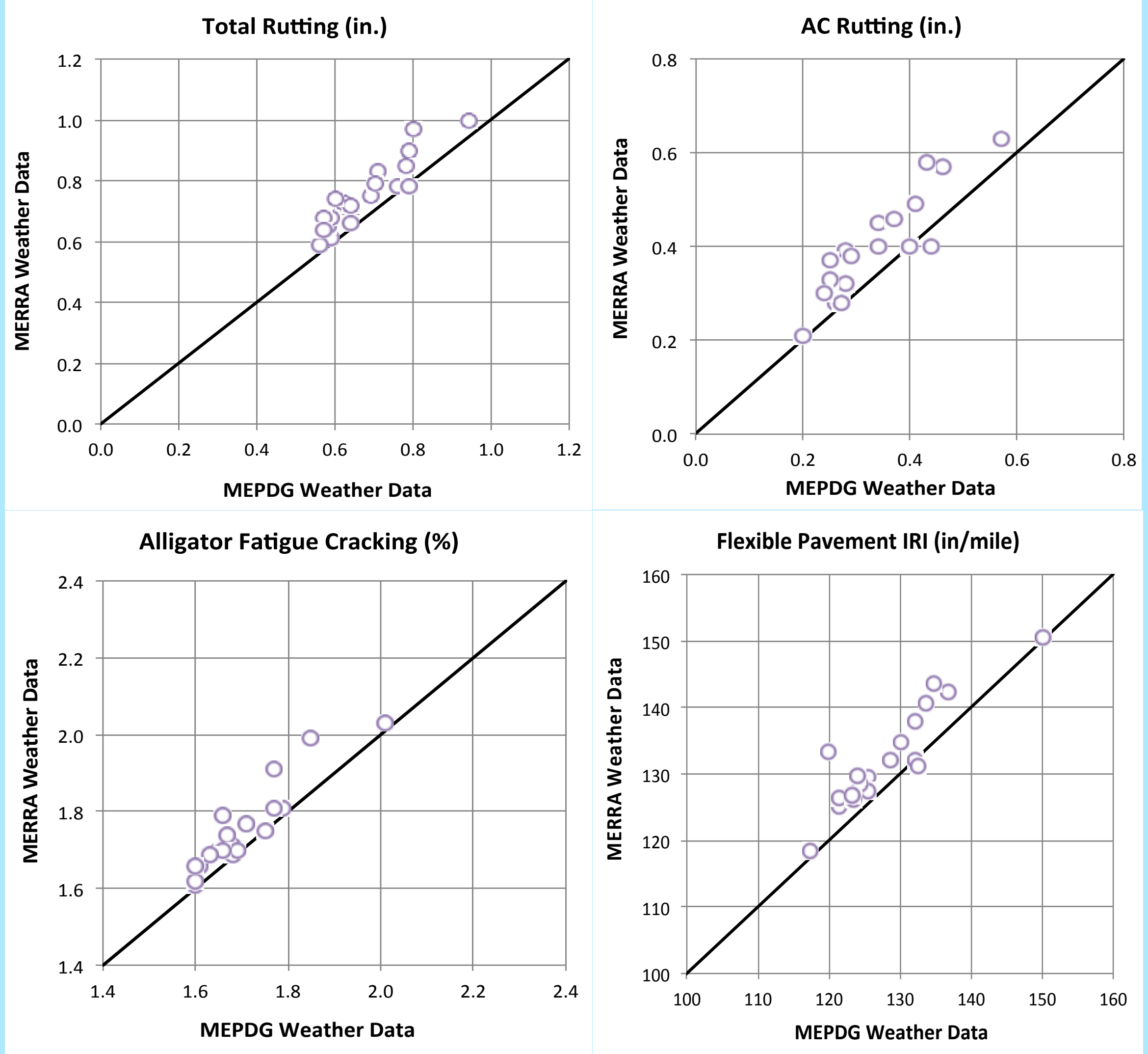
Pavement performance as predicted by the MEDPG models incorporated in the Pavement ME Design® software was evaluated using the MEPDG weather data files provided with the software, which are derived from the QCLCD and Unedited Local Climatological Data (ULCD) products from the National Climatic Data Center (NCDC) and the MERRA climate data for collocated sites and congruent time series. A total of 20 sites distributed randomly across the contiguous United States were analyzed.

It would have been ideal to evaluate MEPDG performance predictions using the USCRN "ground reference" data in addition to the MEDPG and MERRA weather time series. However, the USCRN data do not include the wind speed and cloud cover data required for the MEPDG models. Several attempts were made to synthesize these missing data from other sources, but none were satisfactory.

Both new flexible pavements and new jointed plain concrete pavements (JPCP) were analyzed. The pavement structures, traffic loads, material properties, and other inputs for the analysis correspond to the medium traffic cases for the sensitivity analyses described in Schwartz, et al and Ceylan, et al. (*5, 6*). All analyses were performed using Version 2.0 of the Pavement ME Design® software.

Comparisons of flexible pavement performance as predicted by the MEPDG using MERRA vs. MEPDG weather data are shown in figure 1 for total rutting, asphalt concrete (AC) rutting, alligator fatigue cracking, and roughness. Top-down longitudinal fatigue cracking was not considered because this model is generally viewed as unreasonably sensitive and unrealistic; a replacement for the current top-down fatigue cracking model is currently being developed in NCHRP Project 1-52.

Figure 1. Comparison of MEPDG flexible pavement predictions for total rutting, AC rutting, alligator fatigue cracking, and roughness (IRI) using MERRA vs. MEPDG weather data.


Total Rutting (in.)

AC Rutting (in.)

Alligator Fatigue Cracking (%)

Flexible Pavement IRI (in/mile)

In all cases, the predictions are clustered tightly although not perfectly along the respective lines of equality and show a slightly higher prediction of distress for MERRA. This is consistent with the close but not perfect agreement found among these climate data time series in the statistical comparisons described previously.

Comparisons of rigid JPCP pavement performance as predicted by the MEPDG using MERRA versus MEPDG weather data show that these predictions are also clustered tightly although not perfectly along the respective lines of equality. This is also consistent with the close but not perfect agreement found among these climate data time series in the statistical comparisons described previously. The agreement between the MERRA vs. MEPDG weather data cases for rigid pavement performance is somewhat less than for flexible pavements. However, this is consistent with the fact that rigid pavement performance is more sensitive to shorter term (e.g., diurnal) temperature variations and thus to the differences between MERRA vs. MEPDG weather data over short time periods.

Conclusions

Results of and conclusions from the research include the following points:

The statistical comparisons of hourly temperature data, the meteorological variable most influential on pavement performance, found that the QCLCD and MERRA data have small and roughly comparable differences from the USCRN values. The mean biases in hourly temperatures computed for the QCLCD and MERRA data vs. the USCRN reference values averaged across 275 sites were 0.63 ^{o}C and 1.40 ^{o}C, respectively. The MERRA data are slightly warmer on average than the QCLCD values, but only by less than 1 ^{o}C.

Comparisons of predicted performance using the different sources of weather data are arguably the most relevant for pavement applications. Overall, the comparisons in MEPDG predicted performance for both flexible and rigid pavements using MERRA vs. MEPDG weather data are close and acceptable for engineering design. Based on the statistical comparisons among the various climate data sources, the agreement in predicted performance using MERRA vs. USCRN “ground truth” and/or MEPDG vs. USCRN would likely show similar scatter in agreement as seen in Figure 1. However, it is impossible to demonstrate this because the USCRN data lack the wind speed and cloud cover inputs required by the MEPDG software.

Both the statistical and performance prediction comparisons support the conclusion that MERRA is an acceptable source for climate data that can be used in place of conventional ground-based OWS sources.

Recommendations for LTPP

Based on the results of the research effort, it is recommended that:

1. The LTPP program uses the MERRA dataset as the basis for continuous hourly climate data histories for its test locations.

2. Using the MERRA dataset, LTPP should calculate the same derived computed climate statistics as shown in table 1.

3. The climate module in the LTPP Information Management System (IMS) should be expanded to contain MERRA data for the cells where LTPP test sections are currently located (thus MERRA data and OWS data will exist in the IMS and the users can select the dataset they wish to use).

Implementation of MERRA in the MEPDG

MERRA has shown great promise as a possible supplement or replacement for the weather data currently used in the MEPDG. The benefits, as outlined herein, have the potential to provide a more robust dataset with more granular spatial coverage and higher quality.

Based on the findings of this research, it is recommended that MERRA be considered for implementation within the

MEPDG. As part of this research, a tool is being created to extract MERRA data in a MEPDG-compatible format. This dataset could very easily (1) replace the current weather dataset or (2) be used as a complement to the OWS-based MEDPG dataset. In the case of option 1, the MERRA dataset could easily be formatted similarly to the existing dataset and an algorithm implemented in the MEPDG to select the appropriate MERRA cell(s) for a given project site. If option 2 is considered, the process described in option 1 would be implemented and a checkbox or similar data selection toggle could be presented to users so that they have a choice as to which dataset to use. In either case, the level of effort to implement MERRA in the MEPGD is relatively low and would require very little, if any, additional code to change the underlying MEDPG analytical engine.

A larger and potentially more significant change to the MEPDG analytical engine would be to permit use of the direct prediction of surface shortwave radiation from MERRA. Surface shortwave radiation is the key driver for pavement temperature variation. The MEPDG computes this using top-of-atmosphere solar radiation and an empirical relationship to incorporate diffusion and absorption through the atmosphere. The empirical relationship is both dated and calibrated only to northern tier continental U.S. States and Alaska. MERRA provides direct predictions of surface shortwave radiation, eliminating the empirical correction for diffusion and absorption. The changes to the EICM code to incorporate this would be modest. An additional benefit is that this would eliminate the need for the difficult-to-determine percent cloud cover input currently required by the MEPDG software.

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Additional Information

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