Long-Term Pavement Performance Climate Tool User Guide

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LTPP™

FOREWORD

This document presents the user guide for the Long-Term Pavement Performance (LTPP) online Climate Tool.[1] This Tool provides easy access to climatic data extracted from the National Aeronautics and Space Administration Modern-Era Retrospective Analysis for Research and Applications (MERRA) database. The MERRA dataset is very large and the Tool provides access to this large dataset in an intuitive and easy-to-use format.

The LTPP Climate Tool provides the option to download historical climate data from 1979 to the present. The climatic attributes available are temperature, precipitation, humidity, wind, and solar. The data are available globally in hourly, daily, monthly, and annual increments.

This new Tool provides pavement and bridge engineers and other users with a simplified method for the extraction and processing of worldwide climate data for infrastructure engineering and other applications.

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Director, Office of Infrastructure
Research and Development

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16. Abstract
This report presents the user guide for the Long-Term Pavement Performance (LTPP) Climate Tool. The climate data in the LTPP Climate Tool have been extracted from the National Aeronautics and Space Administration Modern-Era Retrospective Analysis for Research and Applications (MERRA) database. The LTPP Climate Tool was developed to provide convenient dissemination of climate data derived from the MERRA database for infrastructure engineering applications in customary engineering units. This report includes instructions for the use of the LTPP Climate Tool. The Tool includes both a map and a data module that allow the user to download MERRA elements for temperature, precipitation, humidity, wind, and solar at hourly, daily, monthly, and annual time increments all over the world.

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SI* (MODERN METRIC) CONVERSION FACTORS

APPROXIMATE CONVERSIONS TO SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
in	inches	25.4	millimeters	mm
ft	feet	0.305	meters	m
yd	yards	0.914	meters	m
mi	miles	1.61	kilometers	km
		AREA		
in^2	square inches	645.2	square millimeters	mm^2
ft^2	square feet	0.093	square meters	m^2
yd^2	square yard	0.836	square meters	m^2
ac	acres	0.405	hectares	ha
mi^2	square miles	2.59	square kilometers	km^2
		VOLUME		
fl oz	fluid ounces	29.57	milliliters	mL
gal	gallons	3.785	liters	L
ft^3	cubic feet	0.028	cubic meters	m^3
yd^3	cubic yards	0.765	cubic meters	m^3
	NOTE: volumes greater than 1000 L shall be shown in m^3			
		MASS		
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams (or "metric ton")	Mg (or "t")
		TEMPERATURE (exact degrees)		
^oF	Fahrenheit	5 (F-32)/9 or (F-32)/1.8	Celsius	^oC
		ILLUMINATION		
fc	foot-candles	10.76	lux	lx
fl	foot-Lamberts	3.426	$candela/m^2$	cd/m^2
		FORCE and PRESSURE or STRESS		
lbf	poundforce	4.45	newtons	N
lbf/in^2	poundforce per square inch	6.89	kilopascals	kPa

APPROXIMATE CONVERSIONS FROM SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
mm	millimeters	0.039	inches	in
m	meters	3.28	feet	ft
m	meters	1.09	yards	yd
km	kilometers	0.621	miles	mi
		AREA		
mm^2	square millimeters	0.0016	square inches	in^2
m^2	square meters	10.764	square feet	ft^2
m^2	square meters	1.195	square yards	yd^2
ha	hectares	2.47	acres	ac
km^2	square kilometers	0.386	square miles	mi^2
		VOLUME		
mL	milliliters	0.034	fluid ounces	fl oz
L	liters	0.264	gallons	gal
m^3	cubic meters	35.314	cubic feet	ft^3
m^3	cubic meters	1.307	cubic yards	yd^3
		MASS		
g	grams	0.035	ounces	oz
kg	kilograms	2.202	pounds	lb
Mg (or "t")	megagrams (or "metric ton")	1.103	short tons (2000 lb)	T
		TEMPERATURE (exact degrees)		
^oC	Celsius	1.8C+32	Fahrenheit	^oF
		ILLUMINATION		
lx	lux	0.0929	foot-candles	fc
cd/m^2	$candela/m^2$	0.2919	foot-Lamberts	fl
		FORCE and PRESSURE or STRESS		
N	newtons	0.225	poundforce	lbf
kPa	kilopascals	0.145	poundforce per square inch	lbf/in^2

*SI is the symbol for the International System of Units. Appropriate rounding should be made to comply with Section 4 of ASTM E380.
(Revised March 2003)

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LIST OF ABBREVIATIONS

GIS	geographic information system
GUI	graphical user interface
KML	Keyhole Markup Language
LTPP	Long-Term Pavement Performance
ME	Mechanistic-Empirical
MEPDG	*Mechanistic-Empirical Pavement Design Guide*
MERRA	Modern-Era Retrospective Analysis for Research and Applications

CHAPTER 1. INTRODUCTION

BACKGROUND

The Long-Term Pavement Performance (LTPP) Climate Tool was developed as part of the *Evaluation of LTPP Climatic Data for Use in Mechanistic-Empirical Pavement Design Guide (MEPDG) Calibration and Other Pavement Analysis* project.[1,2] The objective of the LTPP Climate Tool development was to provide convenient dissemination of the Modern-Era Retrospective Analysis for Research and Applications (MERRA) climate data for infrastructure engineering applications in customary engineering units.[3]

WHAT IS MERRA DATA?

MERRA, developed by the National Aeronautics and Space Administration, is a physically based global climate–reanalysis product that combines 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 over a vast number of observations. More than 4 million physical observations are ingested during a typical 6-h data assimilation cycle.[3,4] 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 by 65 km at mid-latitudes) at multiple elevations in the atmosphere. Further details regarding MERRA data can be found in the Federal Highway Administration report *Evaluation of LTPP Climatic Data for Use in Mechanistic-Empirical Pavement Design Guide (MEPDG) Calibration and Other Pavement Analysis*.[2]

BENEFITS OF USING LTPP CLIMATE TOOL

The LTPP Climate Tool offers users convenient access to climate data derived from the MERRA process in familiar units to engineers and an efficient means to extract data.[1,3] The MERRA dataset is very large (terabytes), and the Tool provides access to this large dataset in an intuitive and easy-to-use format. The MERRA Climate Data for MEPDG Inputs option under the Tools menu of the LTPP InfoPave™ website offers the ability to extract MERRA data in a format that is compatible with the AASHTOWare® Pavement Mechanistic-Empirical (ME) Design software.[5,6]

CHAPTER 2. AVAILABLE DATA

This chapter provides a brief overview of the data available using the LTPP Climate Tool.[1] The LTPP Climate Tool is capable of providing all of the weather history inputs required by the Pavement ME Design software and other current infrastructure applications.[5] Table 1 contains the hourly data elements available through the LTPP Climate Tool. Data summaries and roll-ups are provided at the daily, monthly, and annual levels. The LTPP Climate Tool provides both raw MERRA data elements, such as precipitation flux, as well as data elements converted to engineering units, such as precipitation. A complete list of the data available through the LTPP Climate Tool is contained in the appendix.

Table 1. Hourly MERRA data elements.

Category	Table Name	Field Name	SI Unit	Description
General	MERRA grid cell identification	MERRA Cell Grid Identifier	—	Unique identification for each MERRA cell
		Latitude	Degree	Latitude of the MERRA cell centroid
		Longitude	Degree	Longitude of the MERRA cell centroid
		Elevation	m	Elevation of the MERRA cell centroid
Solar	MERRA hourly solar	MERRA Cell Grid Identifier	—	Unique identification for each MERRA cell
		Time Stamp	—	Date and time of data recorded
		Shortwave Surface	W/m^2	Surface incident shortwave flux
		Shortwave Top of Atmosphere	W/m^2	TOA incident shortwave flux
		Cloud Cover		Total cloud fraction
		Percent Sunshine	Percent	Total percentage of sky without cloud cover
		Emissivity	W/m^2	Surface emissivity
		Albedo	—	Surface albedo
Humidity	MERRA hourly humidity	MERRA Cell Grid Identifier	—	Unique identification for each MERRA cell
		Time Stamp	—	Date and time of data recorded
		Specific Humidity	kg/kg	Specific humidity at 2 m above the displacement height
		Relative Humidity	Percent	Relative humidity 2 m above MERRA centroid elevation
		Air Pressure	Pa	Time averaged surface pressure
Wind	MERRA hourly wind	MERRA Cell Grid Identifier	—	Unique identification for each MERRA cell
		Time Stamp	—	Date and time of data recorded
		North Wind	m/s	Northward wind at 2 m above displacement height
		East Wind	m/s	Eastward wind at 2 m above displacement height
		Wind Velocity	m/s	Time averaged magnitude of wind velocity 2 m above MERRA centroid elevation
		Air Density	kg/m^3	Surface air density

Category	Table Name	Field Name	SI Unit	Description
Temperature	MERRA hourly temperature	MERRA Cell Grid Identifier	—	Unique identification for each MERRA cell
		Time Stamp	—	Date and time of data recorded
		Hourly Temperature	Kelvin	Temperature at 2 m above the displacement height
		Temperature	Celsius	Temperature at 2 m above the displacement height
		Hourly Soil Temperature Layer 1	Kelvin	Soil temperature in layer 1
		Soil Temperature Layer 1	Celsius	Soil temperature in layer 1
		Hourly Soil Temperature Layer 2	Kelvin	Soil temperature in layer 2
		Soil Temperature Layer 2	Celsius	Soil temperature in layer 2
		Hourly Soil Temperature Layer 3	Kelvin	Soil temperature in layer 3
		Soil Temperature Layer 3	Celsius	Soil temperature in layer 3
		Hourly Soil Temperature Layer 4	Kelvin	Soil temperature in layer 4
		Soil Temperature Layer 4	Celsius	Soil temperature in layer 4
		Hourly Soil Temperature Layer 5	Kelvin	Soil temperature in layer 5
		Soil Temperature Layer 5	Celsius	Soil temperature in layer 5
		Hourly Soil Temperature Layer 6	Kelvin	Soil temperature in layer 6
		Soil Temperature Layer 6	Celsius	Soil temperature in layer 6
		Hourly Soil Temperature Unsaturated Zone	Kelvin	Surface temperature of unsaturated zone
		Soil Temperature Unsaturated Zone	Celsius	Surface temperature of unsaturated zone
		Hourly Soil Temperature Saturated Zone	Kelvin	Surface temperature of saturated zone
		Soil Temperature Saturated Zone	Celsius	Surface temperature of saturated zone
Precipitation	MERRA hourly precipitation	MERRA Cell Grid Identifier	—	Unique identification for each MERRA cell
		Time Stamp	—	Date and time of data recorded
		Precipitation	mm	Water equivalent of total surface precipitation over time period
		Precipitation Flux	$kg/m^2/s$	Total surface precipitation flux
		Evaporation	mm	Water equivalent of total surface evaporation over time period
		Evaporation Flux	$kg/m^2/s$	Surface evaporation
		Infiltration Rate	$kg/m^2/s$	Soil water infiltration rate
		Infiltration	mm	Water equivalent of total infiltration
		Overland Runoff	$kg/m^2/s$	Overland runoff
		Runoff	mm	Water equivalent of total overland runoff over time

Category	Table Name	Field Name	SI Unit	Description
		Snow Melt Rate	$kg/m^2/s$	Snowmelt
		Snow Melt	mm	Snow melt equivalent over time period
		Snow-covered Area Fraction	Fraction	Fractional snow-covered area
		Snowfall Flux	$kg/m^2/s$	Surface snowfall flux
		Snowfall	mm	Snow equivalent of total surface snowfall over time period
Constants	MERRA constants	MERRA Cell Grid Identifier	—	Unique identification for each MERRA cell
		Soil Thickness of saturated and unsaturated zones	m	Thickness of soil layer associated with saturated and unsaturated zone
		Soil Layer 1 Thickness	m	Thickness of soil layer associated with layer 1
		Soil Layer 2 Thickness	m	Thickness of soil layer associated with layer 2
		Soil Layer 3 Thickness	m	Thickness of soil layer associated with layer 3
		Soil Layer 4 Thickness	m	Thickness of soil layer associated with layer 4
		Soil Layer 5 Thickness	m	Thickness of soil layer associated with layer 5
		Soil Layer 6 Thickness	m	Thickness of soil layer associated with layer 6
		Lake Fraction	Fraction	Fraction of lake type in grid box
		Land Fraction	Fraction	Fraction of land type in grid box
		Land Ice Fraction	Fraction	Fraction of land ice type in grid box
		Ocean Fraction	Fraction	Fraction of ocean in grid box

—Dimensionless.
TOA = top of the atmosphere.

DATA ATTRIBUTES

The data attribute types used in the LTPP Climate Tool are temperature, precipitation, humidity, wind, and solar.[1]

DATA FREQUENCY

The data are available in hourly, daily, monthly, and annual increments.

DATA GEOGRAPHIC SCOPE

The data are available globally at an hourly temporal resolution and a horizontal spatial resolution of 0.5 degrees latitude by 0.67 degrees longitude (approximately 50 by 65 km at mid-latitudes) at multiple elevations in the atmosphere.

DATA PROCESSING

The climatic data available through the LTPP Climate Tool have been processed from the standard weather data available from the MERRA website.[1,3] This processing included data offset calculation, computed attributes, and summaries and roll-ups.

As the hourly MERRA data are recorded using Coordinated Universal Time, the climatic data available through the LTPP Climate Tool are offset to the local date/time of the corresponding MERRA cell.[1] The offset is based on the Google® Time Zone Application Programming Interface.

Because many MERRA data elements use climatic units that are not familiar to engineers, such as precipitation flux with units of $kg/m^2/s$, computed attributes provide the data element in traditional engineering units such as precipitation with units of millimeters.

The summary and roll-up values include average, maximum, minimum, standard deviation, and count for daily data based on the hourly values; monthly data based on the number of daily values; and annual data based on monthly values for matching MERRA_ID, day, month, and year.

LTPP CLIMATE TOOL INTERFACE

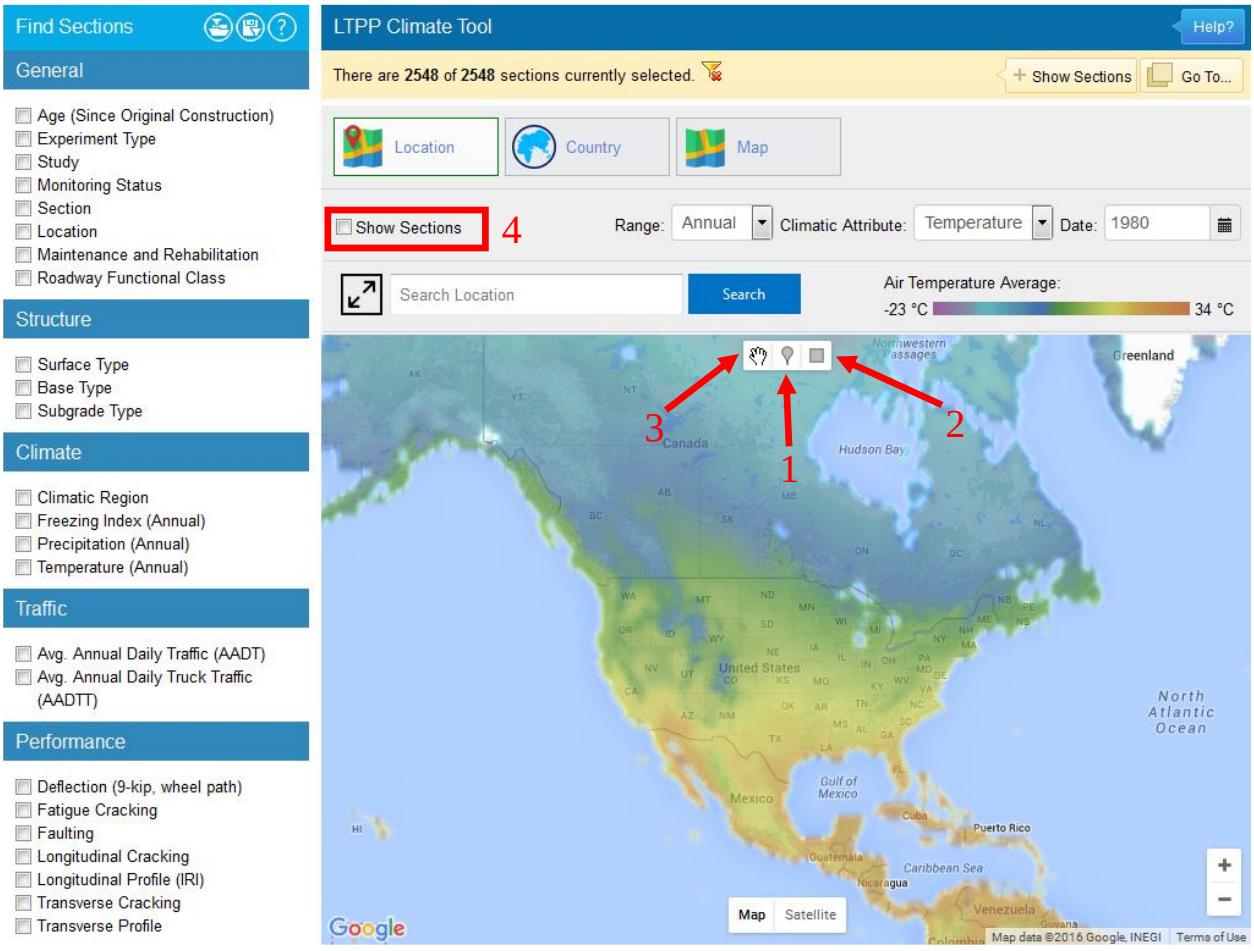
The LTPP Climate Tool can be accessed via the InfoPave™ website under the Data and Tools tabs.[1,6] Once the user selects the LTPP Climate Tool, there are three primary options—by Location, Country, and Map—to select and download the desired data. The Location option allows the user to select the desired data geographically. The Country option allows the user to select the desired data based on the country and State/Province. Both alternatives allow the user to download tabulated or text-based versions of the data. The Map option allows the user to download geographic information system (GIS)-based data in Esri shapefile format or Keyhole Markup Language (KML) file format.

By Location

This section describes the graphical user interface (GUI) features and the functionality provided for the Location module of the LTPP Climate Tool under the Data tab.(1)

The Location module provides the user with a graphical method for selecting data for a desired location. As shown in figure 1, the interface displays the key data element for each selected climatic data attribute according to the selected time frequency on the map. For example, figure 1 shows the average annual air temperature for different locations on the map according to a colored heat map.

There are four main components of the Location module by which the users can make the desired selection: single point data selection, area data selection, pan, and show sections (labeled 1 through 4, respectively, in figure 1).



Source: FHWA.

Figure 1. Screenshot. LTPP Climate Tool Location module.(1)

Single Point Data Selection

The single point data selection tool enables the user to select a single location point on the map and extract climatic data for the specified location. To select a single point on the map, the user must first click on the single point data selection icon (labeled "1" in figure 1) and click on a desired location on the map. The user also has the ability to zoom in on the map by using the zoom controls on the bottom right corner of the map. Once the location is selected, the user is able to extract the data for the desired location for a given frequency (i.e., hourly, monthly, or annual) or for each selected climatic attribute (i.e., precipitation, temperature, wind, humidity, and solar) within a given range of time.

In addition, the user can select a single point on the map by using the search location feature in the Search box. The search location feature automatically selects a location on the map once the search criterion is entered into the search location bar. For example, a user would enter a city/location name into the search field to download the climate data for that location from InfoPave™.[6]

Furthermore, the user is able to choose single or multiple LTPP section locations on the map by using the filters on the left hand side of the LTPP Climate Tool under the Find Sections menu.[1] The Show Sections check box option on the top left of the map allows the viewing of the filtered LTPP sections on the map, and the Show Sections button on the top right provides a list of LTPP sections in each State/Province picked using these filters. The filters on the left-hand side are only provided for filtering through the LTPP test sections. If the user chooses to extract MERRA data for those sections, then the user must either use the single point data selection tool to select one of those locations or use the area selection tool to choose a broader range of locations. Using the single point data selection tool and clicking on the close proximity of an LTPP section on the map will select a climatic data cell surrounding that LTPP section.

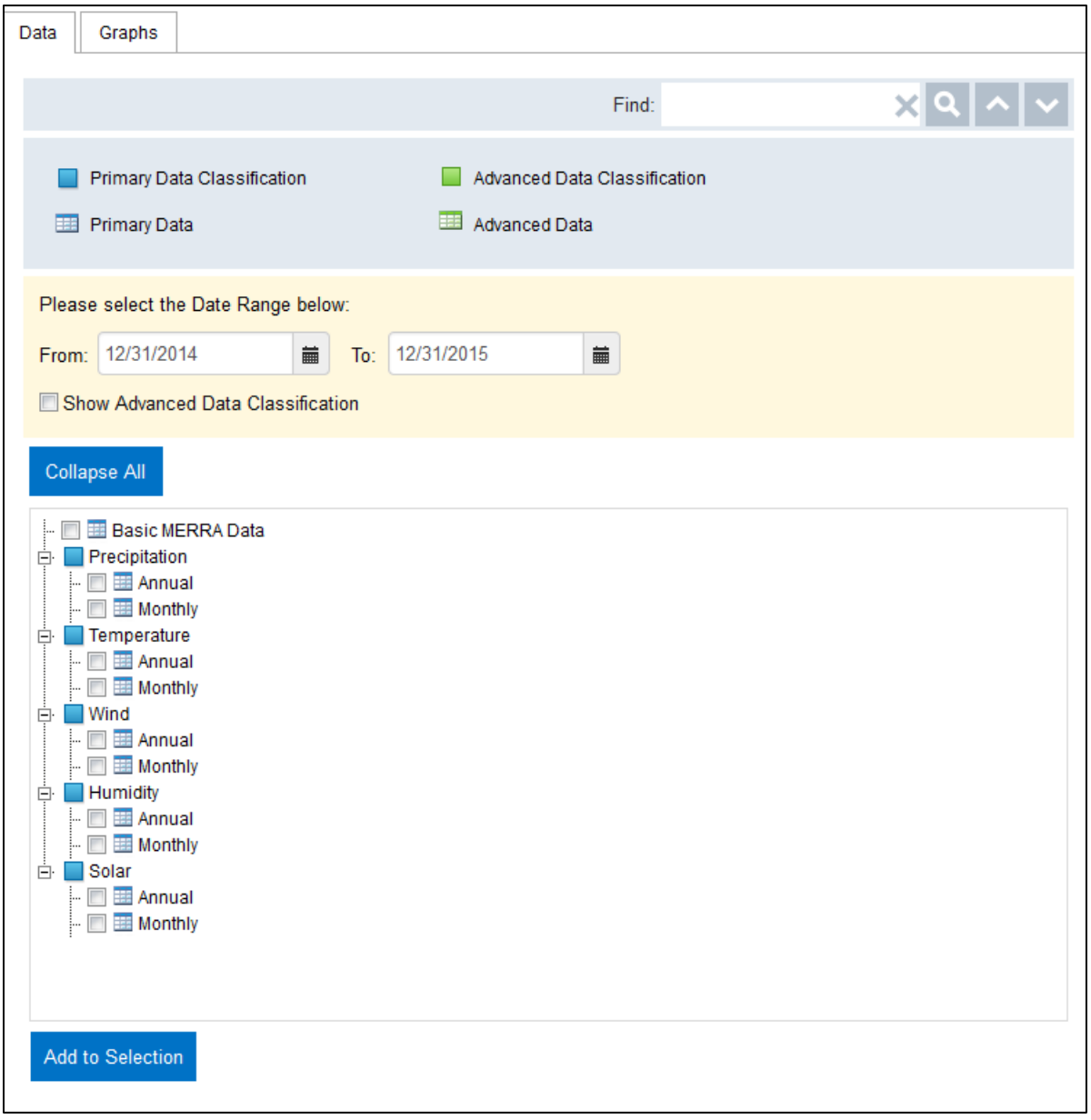
AREA DATA SELECTION TOOL

The area data selection tool, which looks like a square (labeled as "2" in figure 1), enables the user to select a grid of locations for climatic data extraction. To select a region, the user must first click on the area data selection icon and click and drag to highlight a rectangular region on the map for which the data extraction is intended. Once the grid locations are highlighted, the data can be extracted for the highlighted regions for a given frequency (i.e., hourly, monthly, or annual), for each selected climatic attribute (i.e., precipitation, temperature, wind, humidity, and solar) within a given range of time. At this time, only a maximum of 100 grid locations can be selected using the area data selection tool.

DATA TAB

Once a single location is selected using the single point data location tool or multiple locations are selected using the area data selection tool, a data extraction window will appear at the bottom of the page that will allow the user to select the type of data that is to be extracted using the criteria shown in figure 2. As discussed in the Data Frequency section, the user is able to define a range of time period along with the type of climatic data and the frequency of data for the chosen locations. To make the desired frequency and the type of climatic data selection, the user must

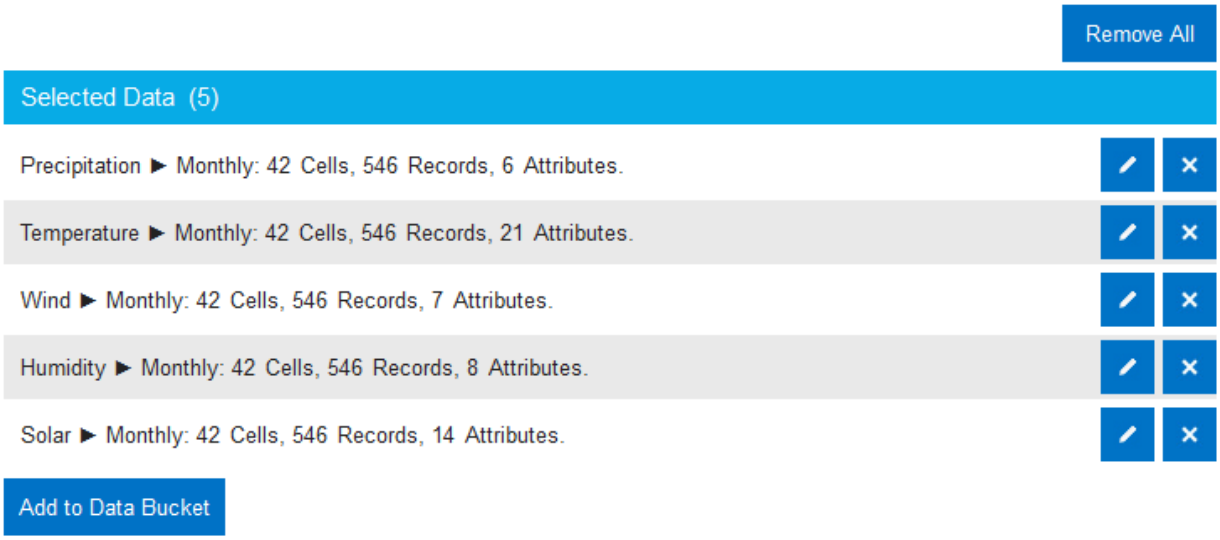
click on the boxes highlighting the type of climatic data and the frequency of the data that is intended for extraction. To change the time period range, the user can simply type in the specified dates within which the data is to be extracted in the From and To bars. In addition, clicking on the icons next to the From and To bars allows the user to simply pick the date from a given calendar.



Source: FHWA.

Figure 2. Screenshot. By location option for data extraction.

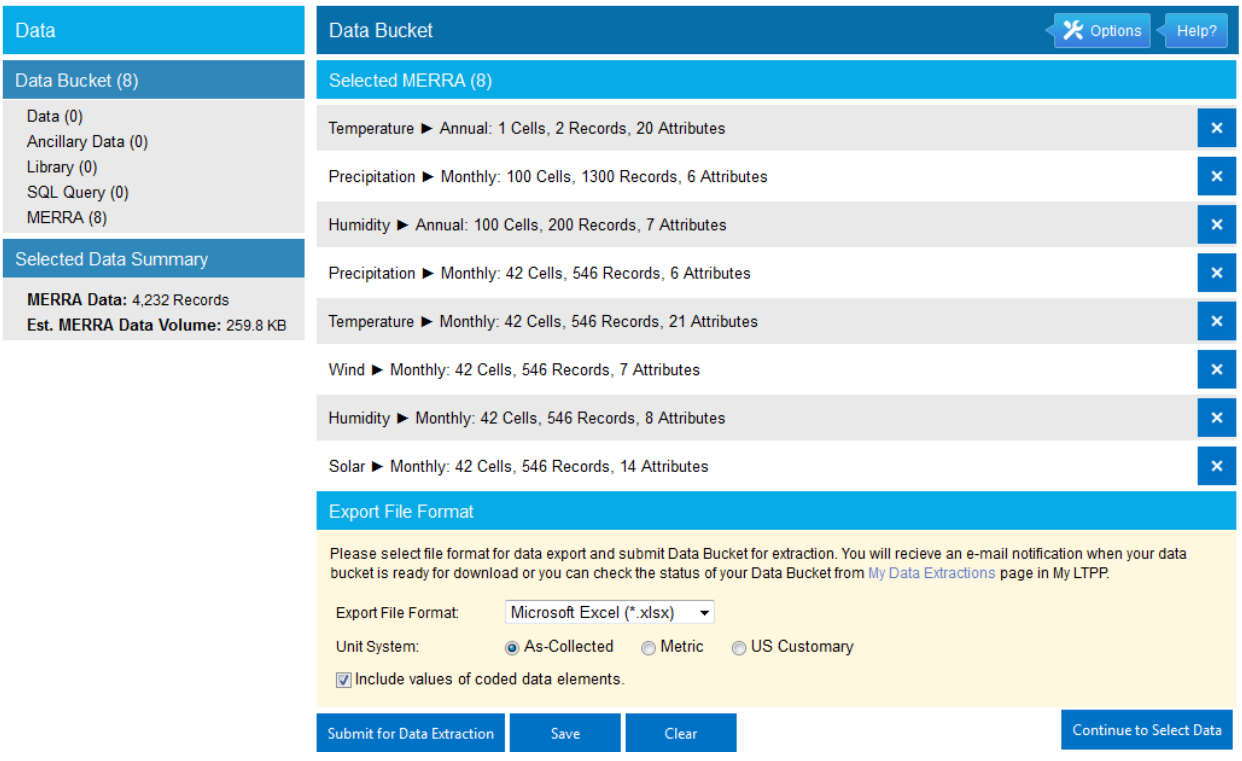
Once the selections are made, the user must click on the Add to Selection icon at the bottom of the screen to proceed to the next step. Clicking on that icon will cause a window to appear at the bottom of the screen that highlights the data chosen for extraction as shown in figure 3.



Source: FHWA.

Figure 3. Screenshot. Add to Data Bucket under location option.

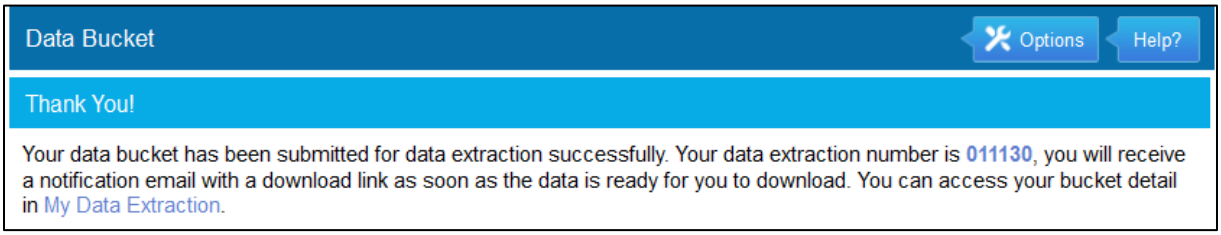
To proceed with the data extraction, the user must click on the Add to Data Bucket icon shown in figure 3. Once this icon is clicked, the selected data is sent to the Data Bucket, which can be opened in a new window as shown in figure 4. The user now also has the option to choose how the data are to be extracted. The selected data can be extracted as a Microsoft® Excel file (.xlsx format), Microsoft® Access database (.mdb format), or Microsoft® SQL database (.bak format).



Source: FHWA.

Figure 4. Screenshot. Data Bucket and data extraction from location option.

To extract the data, the user must click on the Submit for Data Extraction icon, and a window will appear that confirms the data extraction as shown in figure 5.



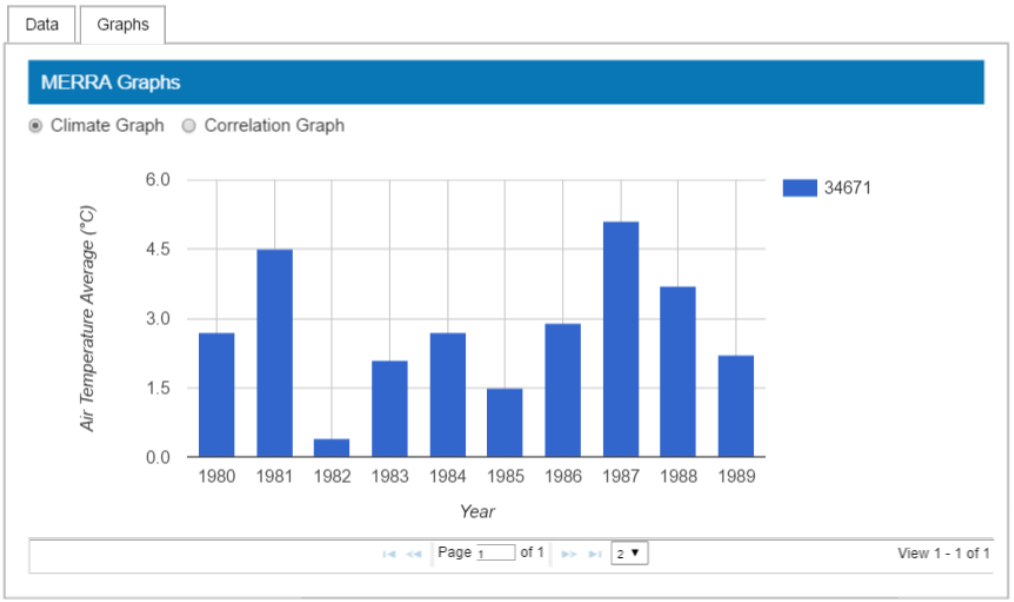
Source: FHWA.

Figure 5. Screenshot. Data extraction confirmation.

An email notification is sent to the user once the data extraction is ready for download. To download the data, the user must click on the download link provided in the email. The data extraction is also available under the MY LTPP tab of the InfoPave™ website.(6)

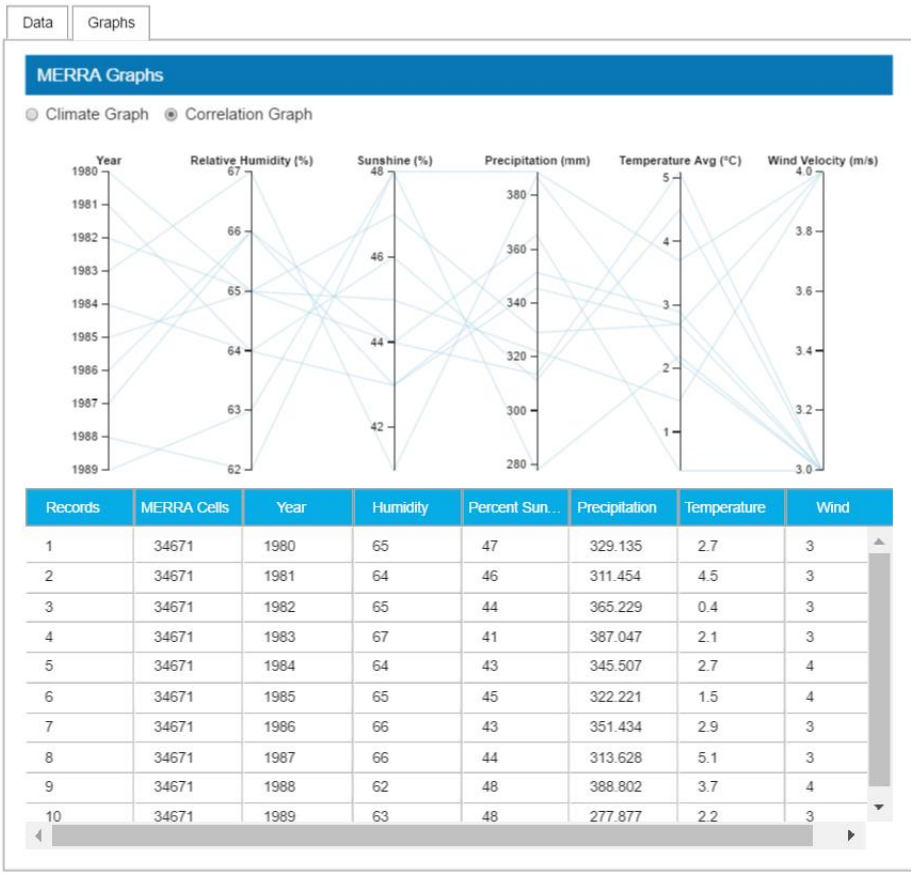
GRAPHS TAB

The Graphs tab is next to the Data tab. With this option, selected data can be visualized in two ways: as a climate bar graph as shown in figure 6 and as a correlation graph as shown in figure 7. The climate graph can extend to multiple pages depending on the selected range of years. The correlation graph shows a linear correlation among the climatic variables (relative humidity, sunshine, precipitation, average temperature, and wind velocity) for the maximum range of 10 yr.



Source: FHWA.

Figure 6. Screenshot. Climate graph from location option.

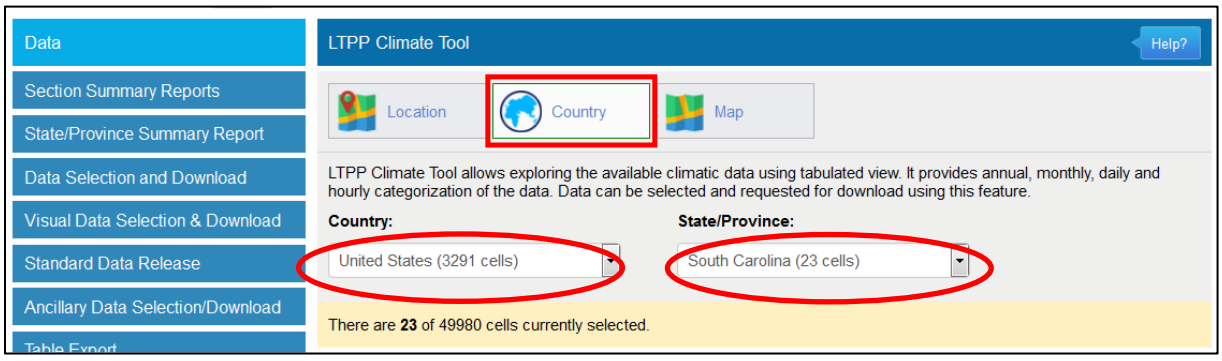


Source: FHWA.

Figure 7. Screenshot. Correlation graph from the location option.

By Country

This section describes the GUI features and the functionality provided for the Country module of the LTPP Climate Tool.(1) The Country module allows a user to select a location by country and State/Province. To select desired data, the user must first choose a country under the location tab as highlighted in figure 8. Once the country and State/Province are selected, the user can follow the same data extraction instructions detailed in the previous section.



Source: FHWA.

Figure 8. Screenshot. Country option.

Map

The Map option provides the user with the alternative to download GIS-based files for the selected attributes (temperature, precipitation, humidity, wind, and radiation) for a selected frequency (annual, monthly, daily, and hourly) and a specific time frame (year, month, date, and hour). The map will include all of the MERRA data cells for the selected time frame, and it can be downloaded either in Esri shapefile (*.shp) or KML (*.kml) format. Figure 9 shows a Google® Earth™ screenshot of the MERRA data for a specific location out of the entire available grid, and figure 10 shows an ArcGIS map displaying the worldwide MERRA data grid.

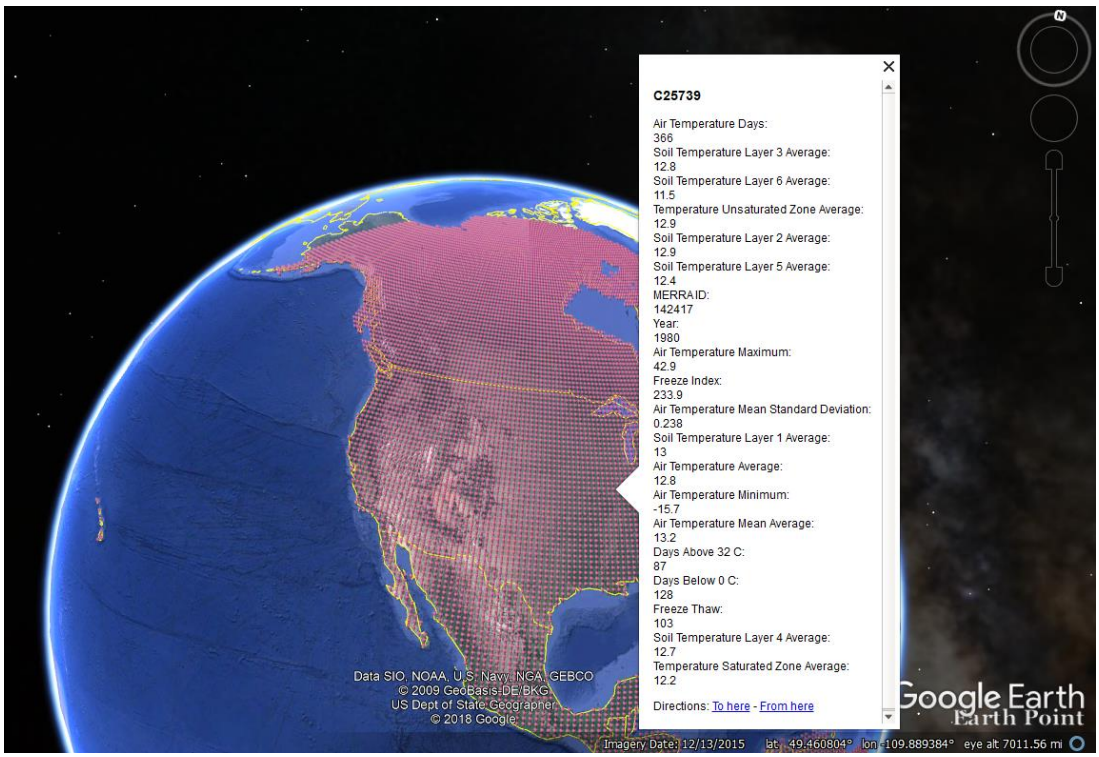


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Figure 9. Map. MERRA grid and selected data.[6,7]

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Figure 10. Map. ArcGIS map showing the worldwide MERRA data grid.

APPENDIX. MERRA DATA ELEMENTS

In this appendix, table 2 presents the details about the location of the MERRA cells. Table 3 describes the MEPDG input data generated from the MERRA Climate Data for MEPDG input option in LTPP InfoPave™.[5] Table 4 through table 24 describe the field name, unit, and description of MERRA database available in the LTPP Climate Tool and are organized by climate attributes (precipitation, temperature, wind, humidity, and solar) and time.

Table 2. MERRA grid cell identification.

Field Name	Unit	Description
MERRA_ID	—	Unique identification for each MERRA cell
LATITUDE	Degree	Latitude of the MERRA cell centroid
LONGITUDE	Degree	Longitude of the MERRA cell centroid
ELEVATION	m	Elevation of the MERRA cell centroid

—Dimensionless.

Table 3. MERRA climate data for MEPDG inputs.

Field Name	Unit	Description
MERRA_ID	—	Unique identification for each MERRA cell
DATE_TIME	—	Date and time of data recorded
TEMPERATURE_COMPUTED	Celsius	Temperature at 2 m above the displacement height in SI units
WIND_VELOCITY	m/s	Computed time averaged magnitude of wind velocity 2 m above MERRA centroid elevation
PERCENT_SUNSHINE	Percent	Computed total percentage of sky without cloud cover
PRECIPITATION	mm	Computed water equivalent of total surface precipitation over time period
RELATIVE_HUMIDITY	Percent	Computed relative humidity 2 m above MERRA centroid elevation

—Dimensionless.

Table 4. MERRA hourly precipitation.

Field Name	Unit	Description
MERRA_ID	—	Foreign Key from MERRA_GRID table
DATE_TIME	—	Date and time of data recorded
PRECIPITATION	mm	Computed water equivalent of total surface precipitation over time period
PRECIP_FLUX	$kg/m^2/s$	Total surface precipitation flux
EVAPORATION	mm	Computed water equivalent of total surface evaporation over time period
EVAPORATION_FLUX	$kg/m^2/s$	Surface evaporation
WATER_INFLITRATION_RATE	$kg/m^2/s$	Soil water infiltration rate
INFILTRATION	mm	Computed water equivalent of total infiltration
OVERLAND_RUNOFF	$kg/m^2/s$	Overland runoff
RUNOFF	mm	Computed water equivalent of total overland runoff over time
SNOW_MELT	$kg/m^2/s$	Snow melt
SNOW_MELT_COMPUTED	mm	Computed snow melt equivalent over time period
FRACTIONAL_SNOW_COV_AREA		Fractional snow-covered area
SNOWFALL_FLUX	$kg/m^2/s$	Surface snowfall flux
SNOWFALL	mm	Computed snow equivalent of total surface snowfall over time period

—Dimensionless.

Table 5. MERRA hourly humidity.

Field Name	Unit	Description
MERRA_ID	—	Foreign Key from MERRA_GRID table
DATE_TIME	—	Date and time of data recorded
SPECIFIC_HUMIDITY	kg/kg	Specific humidity at 2 m above the displacement height
RELATIVE_HUMIDITY	Percent	Computed relative humidity 2 m above MERRA centroid elevation
PRESSURE_HR	Pa	Time averaged surface pressure

—Dimensionless.

Table 6. MERRA hourly temperature.

Field Name	Unit	Description
MERRA_ID	—	Foreign Key from MERRA_GRID table
DATE_TIME	—	Date and time of data recorded
TEMPERATURE	Kelvin	Temperature at 2 m above the displacement height
TEMPERATURE_COMPUTED	Celsius	Temperature at 2 m above the displacement height in SI units
SOIL_TEMP_LAYER1	Kelvin	Soil temperature in layer 1
SOIL_TEMP_LAYER1_COMPUTED	Celsius	Soil temperature in layer 1 in SI units
SOIL_TEMP_LAYER2	Kelvin	Soil temperature in layer 2
SOIL_TEMP_LAYER2_COMPUTED	Celsius	Soil temperature in layer 2 in SI units
SOIL_TEMP_LAYER3	Kelvin	Soil temperature in layer 3
SOIL_TEMP_LAYER3_COMPUTED	Celsius	Soil temperature in layer 3 in SI units
SOIL_TEMP_LAYER4	Kelvin	Soil temperature in layer 4
SOIL_TEMP_LAYER4_COMPUTED	Celsius	Soil temperature in layer 4 in SI units
SOIL_TEMP_LAYER5	Kelvin	Soil temperature in layer 5
SOIL_TEMP_LAYER5_COMPUTED	Celsius	Soil temperature in layer 5 in SI units
SOIL_TEMP_LAYER6	Kelvin	Soil temperature in layer 6
SOIL_TEMP_LAYER6_COMPUTED	Celsius	Soil temperature in layer 6 in SI units
TEMP_UNSAT_ZONE	Kelvin	Surface temperature of unsaturated zone
TEMP_UNSAT_ZONE_COMPUTED	Celsius	Surface temperature of unsaturated zone in SI units
TEMP_SAT_ZONE	Kelvin	Surface temperature of saturated zone
TEMP_SAT_ZONE_COMPUTED	Celsius	Surface temperature of saturated zone in SI units

—Dimensionless.

Table 7. MERRA hourly solar.

Field Name	Unit	Description
MERRA_ID	—	Foreign Key from MERRA_GRID table
DATE_TIME	—	Date and time of data recorded
SHORTWAVE_SURFACE	W/m^2	Surface incident shortwave flux
SHORTWAVE_TOA	W/m^2	TOA incident shortwave flux
CLOUD_COVER	Fraction	Total cloud fraction
PERCENT_SUNSHINE	Percent	Computed total percentage of sky without cloud cover
SURFACE_EMISSIVITY	—	Surface emissivity
SURFACE_ALBEDO	W/m^2	Surface albedo

—Dimensionless.
TOA = top of the atmosphere.

Table 8. MERRA hourly wind.

Field Name	Unit	Description
MERRA_ID	—	Foreign Key from MERRA_GRID table
DATE_TIME	—	Date and time of data recorded
NORTH_WIND	m/s	Northward wind at 2 m above displacement height
EAST_WIND	m/s	Eastward wind at 2 m above displacement height
WIND_VELOCITY	m/s	Computed time averaged magnitude of wind velocity 2 m above MERRA centroid elevation
AIR_DENSITY	kg/m^3	Surface air density

—Dimensionless.

Table 9. MERRA constant.

Field Name	Unit	Description
MERRA_ID	—	Foreign Key from MERRA_GRID table
SOIL_THICKNESS	m	Thickness of soil layer associated with the saturated zone, the unsaturated zone, and the wilting zone surface temperatures
SOIL_THICKNESS_LAYER1	m	Thickness of soil layer associated with the top layer's soil temperature
SOIL_THICKNESS_LAYER2	m	Thickness of soil layer associated with the second layer's soil temperature
SOIL_THICKNESS_LAYER3	m	Thickness of soil layer associated with the third layer's soil temperature
SOIL_THICKNESS_LAYER4	m	Thickness of soil layer associated with the fourth layer's soil temperature
SOIL_THICKNESS_LAYER5	m	Thickness of soil layer associated with the fifth layer's soil temperature
SOIL_THICKNESS_LAYER6	m	Thickness of soil layer associated with the sixth layer's soil temperature
LAKE_TYPE	Fraction	Fraction of lake type in grid box
LAND_TYPE	Fraction	Fraction of land type in grid box
LAND_ICE_TYPE	Fraction	Fraction of land ice type in grid box (const_2d_asm_Nx.FRLANDICE)
OCEAN_TYPE	Fraction	Fraction of ocean in grid box

—Dimensionless.

Table 10. MERRA daily precipitation.

Field Name	Unit	Description
MERRA_ID	—	Foreign Key from MERRA_GRID table
DATE	—	Date of data recorded
PRECIPITATION	mm	Water equivalent of total surface precipitation over time period
EVAPORATION	mm	Surface evaporation over time period
AVAIL_PRECIP_HRS	h	Number of hours of available precipitation data for the day
INFILTRATION	mm	Water equivalent of total infiltration
RUNOFF	mm	Water equivalent of total overland runoff over time period
SNOWFALL	mm	Snow equivalent of total surface snowfall over time period
SNOW MASS	kg	Snow mass over time period
SNOW MELT	mm	Snow melt equivalent over time period

—Dimensionless.

Table 11. MERRA daily humidity.

Field Name	Unit	Description
MERRA_ID	—	Foreign Key from MERRA_GRID table
DATE	—	Date of data recorded
REL_HUM_AVG	Percent	Average relative humidity for the day
REL_HUM_MAX	Percent	Maximum relative humidity for the day
REL_HUM_MIN	Percent	Minimum relative humidity for the day
REL_HUM_STDEV	Percent	Standard deviation of relative humidity for the day
HUMIDITY_HOURS	h	Number of hours of available humidity data for the day

—Dimensionless.

Table 12. MERRA daily temperature.

Field Name	Unit	Description
MERRA_ID	—	Foreign Key from MERRA_GRID table
DATE	—	Date of data recorded
TEMP_AVG	Celsius	Average of the air temperatures 2 m above the MERRA centroid for the day
TEMP_MAX	Celsius	Maximum air temperature 2 m above elevation of MERRA cell centroid for the day
TEMP_MIN	Celsius	Minimum air temperature 2 m above elevation of MERRA cell centroid for the day
TEMP_STDEV	Celsius	Standard deviation of temperatures 2 m above elevation of MERRA cell centroid for the day
TEMP_MEAN	Celsius	Average of the daily maximum and minimum air temperatures 2 m above the MERRA centroid
TEMP_HRS	Celsius	Number of hours of available temperature data for the day
SOIL_TEMP_LAYER1_AVG	Celsius	Average of the soil temperatures for layer 1 for the day
SOIL_TEMP_LAYER2_AVG	Celsius	Average of the soil temperatures for layer 2 for the day
SOIL_TEMP_LAYER3_AVG	Celsius	Average of the soil temperatures for layer 3 for the day
SOIL_TEMP_LAYER4_AVG	Celsius	Average of the soil temperatures for layer 4 for the day
SOIL_TEMP_LAYER5_AVG	Celsius	Average of the soil temperatures for layer 5 for the day
SOIL_TEMP_LAYER6_AVG	Celsius	Average of the soil temperatures for layer 6 for the day
TEMP_UNSAT_ZONE_AVG	Celsius	Average of the surface temperature for the unsaturated zone for the day
TEMP_SAT_ZONE_AVG	Celsius	Average of the surface temperature for the unsaturated zone for the day

—Dimensionless.

Table 13. MERRA daily solar.

Field Name	Unit	Description
MERRA_ID	—	Foreign Key from MERRA_GRID table
DATE	—	Date of data recorded
SHORTWAVE_SURFACE	W/m^2	Total surface incident shortwave radiation for day
SHORTWAVE_TOA	W/m^2	Total top of atmosphere incident shortwave radiation for day
CLOUD_COVER_AVG	Fraction	Average fraction of cloud cover at MERRA cell centroid for the day
PERCENT_SUNSHINE_AVG	Percent	Average percentage of sky without cloud cover for the day
SOLAR_HRS	h	Number of hours of available solar data for the day

—Dimensionless.
TOA = top of the atmosphere.

Table 14. MERRA daily wind.

Field Name	Unit	Description
MERRA_ID	—	Foreign Key from MERRA_GRID table
DATE	—	Date of data recorded
WIND_VELOCITY_AVG	m/s	Time averaged magnitude of wind velocity 2 m above MERRA centroid elevation for the day
WIND_VELOCITY_MAX	m/s	Maximum average wind velocity 2 m above MERRA centroid elevation for the day
WIND_VELOCITY_MIN	m/s	Minimum average wind velocity 2 m above MERRA centroid elevation for the day
WIND_HRS	h	Number of hours of available wind data for the day
AIR_DENSITY_AVG	kg/m^3	Average daily air density

—Dimensionless.

Table 15. MERRA monthly precipitation.

Field Name	Unit	Description
MERRA_ID	—	Foreign Key from MERRA_GRID table
YEAR	yr	Year of data recorded
MONTH	mo	Month of data recorded
PRECIPITATION	mm	Water equivalent of total surface precipitation over year and month time period
EVAPORATION	mm	Surface evaporation over year and month time period
PRECIP_DAYS	d	Number of days in the month with precipitation, snowfall and evaporation data

—Dimensionless.

Table 16. MERRA monthly humidity.

Field Name	Unit	Description
MERRA_ID	—	Foreign Key from MERRA_GRID table
YEAR	yr	Year of data recorded
MONTH	mo	Month of data recorded
REL_HUM_AVG_AVG	Percent	Average daily average relative humidity for the month
REL_HUM_AVG_MAX	Percent	Average maximum daily relative humidity for the month
REL_HUM_AVG_MIN	Percent	Average minimum daily relative humidity for the month
REL_HUM_AVG_STDEV	Percent	Standard deviation of the average daily relative humidity for the month
HUMIDITY_DAYS	d	Number of days in the month with humidity data

—Dimensionless.

Table 17. MERRA monthly temperature.

Field Name	Unit	Description
MERRA_ID	—	Foreign Key from MERRA_GRID table
YEAR	yr	Year of data recorded
MONTH	mo	Month of data recorded
TEMP_AVG	Celsius	Average of the daily air temperatures 2 m above the MERRA centroid for the month
TEMP_MAX	Celsius	Maximum air temperature 2 m above elevation of MERRA cell centroid for the month
TEMP_MIN	Celsius	Minimum air temperature 2 m above elevation of MERRA cell centroid for the month
TEMP_MEAN_AVG	Celsius	Average of the daily mean air temperatures 2 m above the MERRA centroid for the month
TEMP_MEAN_STDEV	Celsius	Standard deviation of the daily mean temperatures 2 m above elevation of MERRA cell centroid for the month
DAYS_ABOVE_32_C	d	Number of days in the month when the maximum air temperature is greater than 32.2 degrees Celsius
DAYS_BELOW_0_C	d	Number of days in the month when the minimum air temperature is less than 0 degrees Celsius
FREEZE_INDEX	Celsius degree days	Summation of difference between 0 and mean daily air temperature, when mean daily air temperature is less than 0 degrees Celsius, for each day of the month
FREEZE_THAW	d	Number of days in the month when the maximum air temperature is greater than 0 degrees Celsius and minimum air temperature is less than 0 degrees Celsius on the same day

Field Name	Unit	Description
TEMP_DAYS	d	Number of days in the month with temperature data
SOIL_TEMP_LAYER1_AVG	Celsius	Average of the daily soil temperatures for layer 1 for the month
SOIL_TEMP_LAYER2_AVG	Celsius	Average of the daily soil temperatures for layer 2 for the month
SOIL_TEMP_LAYER3_AVG	Celsius	Average of the daily soil temperatures for layer 3 for the month
SOIL_TEMP_LAYER4_AVG	Celsius	Average of the daily soil temperatures for layer 4 for the month
SOIL_TEMP_LAYER5_AVG	Celsius	Average of the daily soil temperatures for layer 5 for the month
SOIL_TEMP_LAYER6_AVG	Celsius	Average of the daily soil temperatures for layer 6 for the month
TEMP_UNSAT_ZONE_AVG	Celsius	Average of the daily surface temperature for the unsaturated zone for the month
TEMP_SAT_ZONE_AVG	Celsius	Average of the daily surface temperature for the unsaturated zone for the month

—Dimensionless.

Table 18. MERRA monthly solar.

Field Name	Unit	Description
MERRA_ID	—	Foreign Key from MERRA_GRID table
YEAR	yr	Year of data recorded
MONTH	mo	Month of data recorded
SHORTWAVE_SURFACE	W/m^2	Summation of total surface incident shortwave radiation for the month
SHORTWAVE_TOA	W/m^2	Summation of total top of atmosphere incident shortwave radiation for the month
SHORTWAVE_SURFACE_AVG	W/m^2	Average daily surface shortwave radiation for the month
SHORTWAVE_SURFACE_STDEV	W/m^2	Standard deviation of the daily surface shortwave radiation for the month
CLOUD_COVER_AVG	Fraction	Average daily fraction of cloud cover at MERRA cell centroid for the month
PERCENT_SUNSHINE_AVG	Percent	Average daily percentage of sky without cloud cover for the month
SOLAR_DAYS	d	Number of days in the month with solar data

—Dimensionless.
TOA = top of the atmosphere.

Table 19. MERRA monthly wind.

Field Name	Unit	Description
MERRA_ID	—	Foreign Key from MERRA_GRID table
YEAR	yr	Year of data recorded
MONTH	mo	Month of data recorded
WIND_VELOCITY_AVG	m/s	Time averaged magnitude of wind velocity 2 m above MERRA centroid elevation for the month
WIND_VELOCITY_MAX	m/s	Maximum average wind velocity 2 m above MERRA centroid elevation for the month
WIND_VELOCITY_MIN	m/s	Minimum average wind velocity 2 m above MERRA centroid elevation for the month
WIND_DAYS	d	Number of days in the month with wind data

—Dimensionless.

Table 20. MERRA yearly precipitation.

Field Name	Unit	Description
MERRA_ID	—	Foreign Key from MERRA_GRID table
YEAR	yr	Year of data recorded
PRECIPITATION	mm	Water equivalent of total surface precipitation over year time period
EVAPORATION	mm	Surface evaporation over year time period
PRECIP_DAYS	d	Number of days in the year with precipitation, snowfall and evaporation data

—Dimensionless.

Table 21. MERRA yearly humidity.

Field Name	Unit	Description
MERRA_ID	—	Foreign Key from MERRA_GRID table
YEAR	yr	Year of data recorded
REL_HUM_AVG_AVG	Percent	Average monthly average relative humidity for the year
REL_HUM_AVG_MAX	Percent	Average maximum monthly relative humidity for the year
REL_HUM_AVG_MIN	Percent	Average minimum monthly relative humidity for the year.
REL_HUM_AVG_STDEV	Percent	Standard deviation of the average monthly relative humidity for the year
HUMIDITY_DAYS	d	Number of days in the year with available humidity data

—Dimensionless.

Table 22. MERRA yearly temperature.

Field Name	Unit	Description
MERRA_ID	—	Foreign Key from MERRA_GRID table
YEAR	yr	Year of data recorded
TEMP_AVG	Celsius	Average of the air temperatures 2 m above the MERRA centroid for the year
TEMP_MAX	Celsius	Maximum air temperature 2 m above elevation of MERRA cell centroid for the year
TEMP_MIN	Celsius	Minimum air temperature 2 m above elevation of MERRA cell centroid for the year
TEMP_MEAN_AVG	Celsius	Average of the monthly mean air temperatures 2 m above the MERRA centroid for the year
TEMP_MEAN_STDEV	Celsius	Standard deviation of the monthly mean temperatures 2 m above elevation of MERRA cell centroid for the year
DAYS_ABOVE_32_C	d	Number of days in the year when the maximum air temperature is greater than 32.2 degrees Celsius
DAYS_BELOW_0_C	d	Number of days in the year when the minimum air temperature is less than 0 degrees Celsius
FREEZE_INDEX	Celsius degree days	Summation of difference between 0 degrees Celsius and mean daily air temperature, when mean daily air temperature is less than 0 degrees Celsius
FREEZE_THAW	d	Number of days in the year when the maximum air temperature is greater than 0 degrees Celsius and minimum air temperature is less than 0 degrees Celsius on the same day
TEMP_DAYS	d	Numbers of days in the year with available temperature data
SOIL_TEMP_LAYER1_AVG	Celsius	Average of the mean soil temperatures for layer 1 for the year
SOIL_TEMP_LAYER2_AVG	Celsius	Average of the mean soil temperatures for layer 2 for the year
SOIL_TEMP_LAYER3_AVG	Celsius	Average of the mean soil temperatures for layer 3 for the year
SOIL_TEMP_LAYER4_AVG	Celsius	Average of the mean soil temperatures for layer 4 for the year
SOIL_TEMP_LAYER5_AVG	Celsius	Average of the mean soil temperatures for layer 5 for the year
SOIL_TEMP_LAYER6_AVG	Celsius	Average of the mean soil temperatures for layer 6 for the year
TEMP_UNSAT_ZONE_AVG	Celsius	Average of the mean surface temperature for the unsaturated zone for the year
TEMP_SAT_ZONE_AVG	Celsius	Average of the mean surface temperature for the saturated zone for the year

—Dimensionless.

Table 23. MERRA yearly solar.

Field Name	Unit	Description
MERRA_ID	—	Foreign Key from MERRA_GRID table
YEAR	yr	Year of data recorded
SHORTWAVE_SURFACE	W/m^2	Summation of total surface incident shortwave radiation for the year
SHORTWAVE_TOA	W/m^2	Summation of total top of atmosphere incident shortwave radiation for the year
SHORTWAVE_SURFACE_AVG	W/m^2	Average surface shortwave radiation for the year
SHORTWAVE_SURFACE_STDEV	W/m^2	Standard deviation of the surface shortwave radiation for the year
CLOUD_COVER_AVG	Fraction	Average fraction of cloud cover at MERRA cell centroid for the year
PERCENT_SUNSHINE_AVG	Percent	Average percentage of sky without cloud cover for the year
SOLAR_DAYS	d	Number of days in the year with available solar radiation and cloud cover data

—Dimensionless.
TOA = top of the atmosphere.

Table 24. MERRA yearly wind.

Field Name	Unit	Description
MERRA_ID	—	Foreign Key from MERRA_GRID table
YEAR	yr	Year of data recorded
WIND_VELOCITY_AVG	m/s	Time averaged magnitude of wind velocity 2 m above MERRA centroid elevation for the year
WIND_VELOCITY_MAX	m/s	Maximum average wind velocity 2 m above MERRA centroid elevation for the year
WIND_DAYS	d	Numbers of days in the year with available wind data

—Dimensionless.

REFERENCES

1. FHWA. (2016). *LTPP Climate Tool,* Federal Highway Administration, Washington, DC, obtained from: https://infopave.fhwa.dot.gov/Data/ClimateTool, last accessed December 1, 2016.

2. Schwartz, C. H., Elkins, G. E., Li, R., Visintine, B. A., Forman, B., Rada, G. R., and Groeger, J. L. (2015). *Evaluation of LTPP Climatic Data for Use in Mechanistic-Empirical Pavement Design Guide (MEPDG) Calibration and Other Pavement Analysis, Report No. FHWA-HRT-15-019,* Federal Highway Administration, Washington, DC.

3. NASA. (2015). *MERRA: Modern-Era Retrospective Analysis for Research and Applications,* Goddar Space Flight Center, Global Modeling and Assimilation Office, Greenbelt, MD, obtained from: http://gmao.gsfc.nasa.gov/merra/, last accessed March 9, 2015.

4. Rienecker, M. M., Suarez, M. J., Gelaro, R., Todling, R., Bacmeister, J., Liu, E., Bosilovich, M. G., et al. "MERRA: NASA's Modern-Era Retrospective Analysis for Research and Applications." *Journal of Climate, 24*(14), 3624–3648.

5. AASHTO. (2015). *AASHTOWare® Pavement ME Design,* American Association of State and Highway Transportation Officials, Washington, DC.

6. FHWA. (2016). *LTPP Infopave™*, Federal Highway Administration, Washington, DC, obtained from: https://infopave.fhwa.dot.gov/, last accessed December 15, 2016.

7. Google® Earth™ V.7.1.8.3036. (2016). "North America Region." *Imagery Data: 12/13/2015*, Data SIO, NOAA, U.S. Navy, NGA, GEBCO (lat 49.460804º, lon –109.889384º, eye alt 7011.56). Available at: http://www.google.com/earth/index.html. Last accessed March 01, 2018

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