Louisiana Transportation Research Center

Final Report 574

Building Accurate Historic and Future Climate MEPDG Input Files for Louisiana DOTD

by

Michael Heitzman and Geng Wei
National Center for Asphalt Technology, Auburn University
Saeed Maghsoodloo
Thunderhead Testing
David Timm
Department of Civil Engineering, Auburn University
Gene Takle and Daryl Herzmann
Climate Science Program, Iowa State University

4101 Gourrier Avenue | Baton Rouge, Louisiana 70808
(225) 767-9131 | (225) 767-9108 fax | www.ltrc.lsu.edu

TECHNICAL REPORT STANDARD PAGE

1. Report No. **FHWA/12-2P/574**	**2. Government Accession No.**	**3. Recipient's Catalog No.**
4. Title and Subtitle **Building Accurate Historic and Future Climate MEPDG Input Files for Louisiana DOTD**	**5. Report Date** February 2017 **6. Performing Organization Code** LTRC Project Number: 12-2P SIO # 30000425	
7. Author(s) Michael Heitzman, Geng Wei, Saeed Maghsoodloo, David Timm, Gene Takle, Daryl Herzmann	**8. Performing Organization Report No.**	
9. Performing Organization Name and Address National Center for Asphalt Technology Auburn University Auburn, Alabama	**10. Work Unit No.** **11. Contract or Grant No.**	
12. Sponsoring Agency Name and Address Louisiana Department of Transportation and Development P.O. Box 94245 Baton Rouge, LA 70804-9245	**13. Type of Report and Period Covered** **Interim Report** **July 2011 – November 2016** **14. Sponsoring Agency Code** **LTRC**	
15. Supplementary Notes **Conducted in Cooperation with the U.S. Department of Transportation, Federal Highway Administration**		

16. Abstract

The pavement design process (originally MEPDG, then DARWin-ME, and now Pavement ME Design) requires a multi-year set of hourly climate input data that influence pavement material properties. In Louisiana, the software provides nine locations with climate stations that contain less than ten years of data. This data must be repeated multiple times in the pavement analysis to cover the predicted pavement performance period. This study applied climate science to create 40-year climate files for each of the 64 parishes. Historic climate files start in 1970. Future climate files applied global and regional models to adjust the historic data for forecasted changes over 70 years. Random climate files divided the naturally occurring four- to seven-year climate cycles, randomly sequenced the cycles, and then applied the future adjustment. The final set of climate files placed the cycles into high/low intensity sequences for examining the impact of temperature and precipitation on predicted pavement performance. The historic climate input should be used to calibrate the Pavement ME Design performance models. The random climate input should be used for future pavement designs. The high/low intensity climate input did not generate expected performance trends and needs to be further studied.

17. Key Words Pavement design, climate input, global climate model, predicted pavement performance		**18. Distribution Statement** Unrestricted. This document is available through the National Technical Information Service, Springfield, VA 21161.	
19. Security Classif. (of this report)	**20. Security Classif. (of this page)**	21. No. of Pages: 66	22. Price

Project Review Committee

Each research project will have an advisory committee appointed by the LTRC Director. The Project Review Committee is responsible for assisting the LTRC Administrator or Manager in the development of acceptable research problem statements, requests for proposals, review of research proposals, oversight of approved research projects, and implementation of findings.

LTRC appreciates the dedication of the following Project Review Committee Members in guiding this research study to fruition.

LTRC Administrator/Manager
Zhongjie Zhang
Research Administrator/Manager

Members
Simoine Ardoin
Christophe Fillastre
Mark Ordogne
Xingwei Chen
Jonathan Lachney
Jeff Lambert

Directorate Implementation Sponsor
Janice P. Williams, P.E.
Chief Engineer

Building Accurate Historic and Future Climate MEPDG Input Files for Louisiana DOTD

by

Michael Heitzman
Geng Wei
National Center for Asphalt Technology
Auburn University

Saeed Maghsoodloo
Thunderhead Testing

David Timm
Department of Civil Engineering
Auburn University

Gene Takle
Climate Science Program
Iowa State University

Daryl Herzmann
Climate Science Program
Iowa State University

LTRC 12-2P
SIO # 30000425
conducted for
Louisiana Department of Transportation and Development
Louisiana Transportation Research Center

February 2017

ABSTRACT

The pavement design process (originally Mechanistic Empirical Pavement Design Guide (MEPDG), then DARWin-ME, and now Pavement ME Design) requires a multi-year set of hourly climate input data that influence pavement material properties. In Louisiana, the software provides nine locations with climate stations that contain less than 10 years of data. This data must be repeated multiple times in the pavement analysis to cover the predicted pavement performance period. This study applied climate science to create 40-year climate files for each of the 64 parishes. Historic climate files start in 1970. Future climate files applied global and regional models to adjust the historic data for forecasted changes over 70 years. Random climate files divided the naturally occurring four- to seven-year climate cycles, randomly sequenced the cycles, and then applied the future adjustment. The final set of climate files placed the cycles into high/low intensity sequences for examining the impact of temperature and precipitation on predicted pavement performance.

The historic climate input should be used to calibrate the Pavement ME Design performance models. The random climate input should be used for future pavement designs. The high/low intensity climate input did not generate expected performance trends and needs to be studied further.

ACKNOWLEDGMENTS

The authors wish to thank the DOTD Materials Division under the direction of Chris Abadie and LTRC under the direction of Harold "Skip" Paul for funding this project. Special recognition goes to Kevin Gaspard for his contributions coordinating and guiding the research effort. His contributions helped make for a successfully completed project and this report.

IMPLEMENTATION STATEMENT

The climate files created by this study can be used for calibration and use of the AASHTO Pavement ME design software. Historic climate files should be used for calibrating the performance prediction models to more accurately predict pavement performance in Louisiana. A historic file with 40 years of hourly data is provided for each parish. Random future climate files should be used as input for designing pavements because they better reflect modeled future climate, temperature, and precipitation conditions. A random future climate file with 40 years of hourly data is provided for each of the nine climate zones.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

INTRODUCTION

The new pavement design process (originally MEPDG, then DARWin-ME, and now Pavement ME Design) requires two types of inputs to influence the prediction of pavement distress for a selected set of pavement materials and structure. One input is traffic, more specifically, truck axle loadings. The other input is climate, a multi-year set of hourly data including temperature, precipitation, wind speed, humidity, and percent sunshine. The climate data is then transformed into temperature gradients that influence pavement material properties. For this study, the term MEPDG is used and refers to all of the software versions and name changes.

When the MEPDG was initially launched in 2007, the climate files were generally five to ten years of data, some were incomplete records (gaps in the continuous hourly data), and files started with climate data in the 1990s. As the MEPDG developed, more data was added to many files and incomplete files were corrected or omitted. The location and length of climate files in Louisiana at the time this study was proposed in 2011 are listed in Table 1. The most common geographic locations of MEPDG climate data files are associated with regional and large airports. Although there were 11 files, the distribution of the files across the state was limited, as shown in Figure 1. The five climate files in the northern half of the state only represent three locations. A pavement analysis would require the use of a climate record that may not be near the project location and would require the same climate data to be repeated to complete a 20- to 40-year pavement distress prediction period.

Table 1
MEPDG climate files

ID	Name	Location	Latitude	Longitude	Months
13935	Alexandria, LA	Esler Regional Airport	31.23	-92.18	118
93915	Alexandria, LA	Alexandria International Airport	31.2	-92.34	80
13970	Baton Rouge, LA	Baton Rouge Metro Ryan Field Airport	30.32	-91.09	118
13976	Lafayette, LA	Lafayette Regional Airport	30.12	-91.59	92
3937	Lake Charles, LA	Lake Charles Regional Airport	30.07	-93.14	118
13942	Monroe, LA	Monroe Regional Airport	32.31	-92.02	94
53915	New Iberia, LA	Acadiana Regional Airport	30.02	-91.53	95
12916	New Orleans, LA	Louis Armstrong New Orleans International Airport	29.59	-90.15	118
13957	Shreveport, LA	Shreveport Regional Airport	32.27	-93.49	118
53905	Shreveport, LA	Shreveport Downtown Airport	32.32	-93.44	107
53865	Slidell, LA	Slidell Airport	30.2	-89.49	92

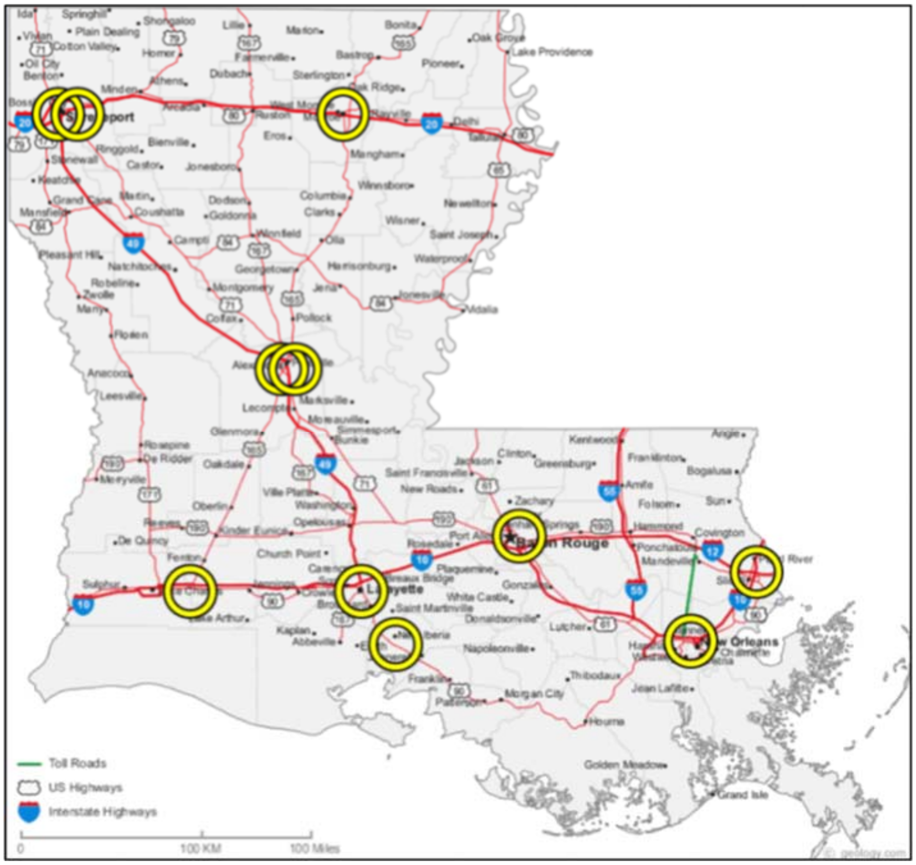


Figure 1
Location of MEPDG climate files in Louisiana

This study applies climate science to improve the depth and length of climate data so the pavement engineer can apply the best climate input data when examining a pavement design. There is a deeper body of climate history and significantly more climate stations to draw from. The climatologist can assemble longer, higher quality climate history files and convert those files using global climate models into data representing a predicted future climate.

After the more in-depth historic and future files are assembled, the study examines the impact of these files on predicted pavement performance. For this part of the study, a single climate file location was randomly selected in each of the state's nine climate zones. Figure 2 shows the distribution of the nine zones and the location of the selected climate file.

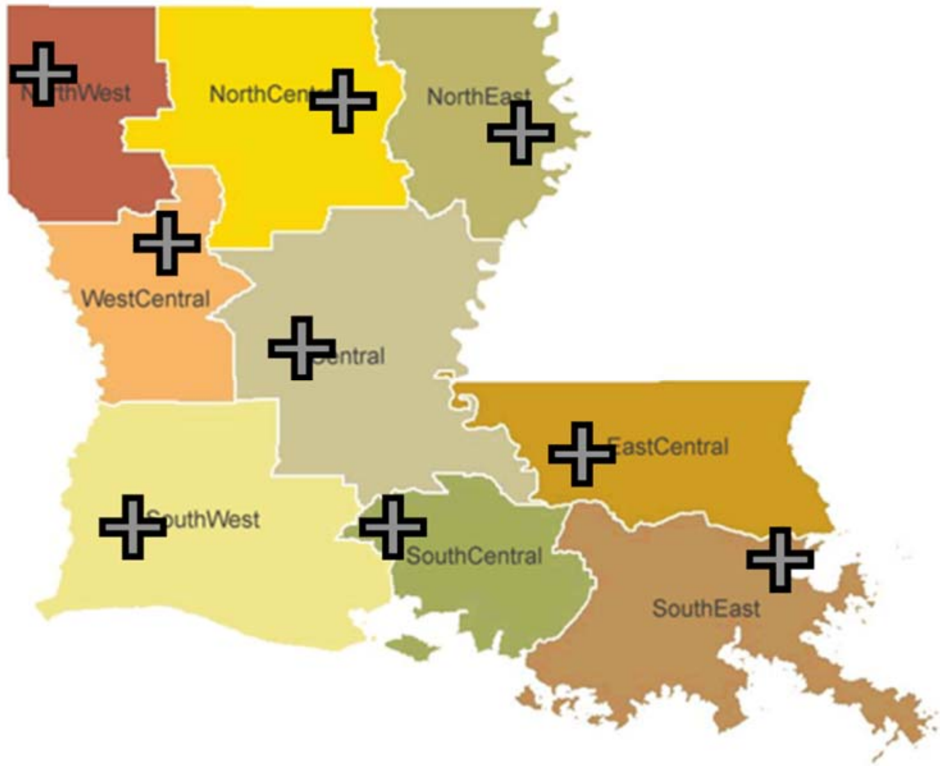


Figure 2
Climate zones and selected climate locations

OBJECTIVE

The objective of this study was to apply the best available climate science to build climate input files for use in the MEPDG. The objective was expanded to consider the naturally occurring cycles in climate temperature and precipitation.

SCOPE

The scope of the study is described in the following tasks.

1. Assemble the available climate data for Louisiana and surrounding states. Data from neighboring states improves the analysis in border parishes.
2. Process the climate data to achieve quality 40-year hourly input values. Format the processed database into MEPDG input files for each of the 64 parishes.
3. Process one 40-year historic climate database in each of the nine state climate zones into a 40-year future climate database incorporating the predictions of available global and regional climate model data.
4. Randomly sort the climate cycles in the nine selected 40-year historic databases and apply the global/regional prediction model to develop 40-year random future climate databases.
5. Format the future and random future databases into MEPDG input files for each of the 64 parishes in the state.
6. Sort the climate cycles in the nine selected 40-year historic databases into extreme temperature and precipitation 40-year climate databases.

METHODOLOGY

Developing Historic Climate Files

The first step was to generate a historic climate file for each parish in Louisiana and assemble the climate data in electronic format required for input into MEPDG model. By building a climate file for each parish, a pavement designer can simply select the climate file for the parish where a project is located. The appropriate historic length of time for these data was established as 1970 through 2009. Every parish does not have a site with an observational record for that period, so an interpolation method in space and time was used to fill in data gaps.

The Automated Surface Observation System (ASOS) and the Cooperative Observer Program (COOP) were two sources used to generate historical climate files. For the 40-year time period and types of data needed for this study, these are the only two sources of data archives available.

The observation platforms in the ASOS archive are primarily automated equipment located at airports. Prior to installing automated systems in the 1980s and 1990s, airport personnel manually reported observations on an hourly basis with the exception of night hours at some locations. Larger airports had overnight manual weather observations. Since 1996, a similar type of observation system called Automated Weather Observation System (AWOS) has also been used. Typically, the ASOS system is maintained by United States government entities, while the AWOS system is operated by the state government. While AWOS sites are technically different than ASOS sites, the ASOS term is broadly used in the literature to include both ASOS and AWOS systems. The ASOS data was one source used to create the MEPDG climate data files.

The COOP observations are once-daily climate observations administered by the National Weather Service (NWS). These observations are the backbone of climate monitoring in the United States and provide relatively dense coverage compared to the number of ASOS/AWOS sites. Reliable daily observations of high and low temperature and rainfall exist for the 40-year period of interest. Observations are subject to a quality control review by technical groups, such as the National Centers for Environmental Information (NCEI) and the NWS.

A summary of the procedural steps taken to assemble historic climate files is illustrated as a flow chart in Figure 3 and consists of the following steps:

1. Collect an archive of daily and hourly observations and check the quality of the data.
2. Produce gridded data using an interpolation analysis of available data.
3. Generate grid-point data sets and produce .hcd files for MEPDG.
4. Check the quality of the .hcd files to ensure no processing errors have occurred.

The scope of each activity undertaken in the above steps is summarized below.

Step 1: Collect Archived Data and Check the Quality of the Data

The challenging aspect for assembling climatic data files for MEPDG is the requirement of hourly data. The variables needed for each hour are:

- *Air Temperature* (units: degrees Fahrenheit) is the measured air temperature at approximately 6.5 ft. above the ground surface. The value is typically measured at the top of the hour and is valid for the minute interval prior to measurement.
- *Wind Speed* (units: miles per hour) is the measured speed of the air at approximately 32.5 ft. above the ground surface. This value is typically an averaged wind speed over a two-minute period instead of an instantaneous value.
- *Percent Sunshine* (0% is cloudy and 100% is clear) is the opposite of percent cloud cover. MEPDG labels this as “sunshine,” but the measured value relates to the degree of cloud cover. The technique used to measure cloud cover with the automated ASOS/AWOS sensors changed during the 40-year time interval used for this study. Prior to the late 1980s, the technique divided the sky into octants and counted the sections covered by clouds. The present-day sensors attempt to estimate a bulk value of sky coverage by producing four distinct categories of sky coverage at three altitudes. For this study, the altitude level with the most dense cloud coverage was used and converted to percent sunshine data.
- *Precipitation* (units: inches) is the accumulated precipitation amount for the previous hour. For example, the value at 6:00 a.m. represents the period of time beginning at 5:00 a.m. and ending at 6:00 a.m.
- *Relative Humidity* (units: percent) is the measured concentration of water vapor in the atmosphere divided by potential water vapor capacity at the measured air temperature. This measurement is valid at the same 6.5-ft. height of the air temperature and for the same one-minute period prior to observation time.

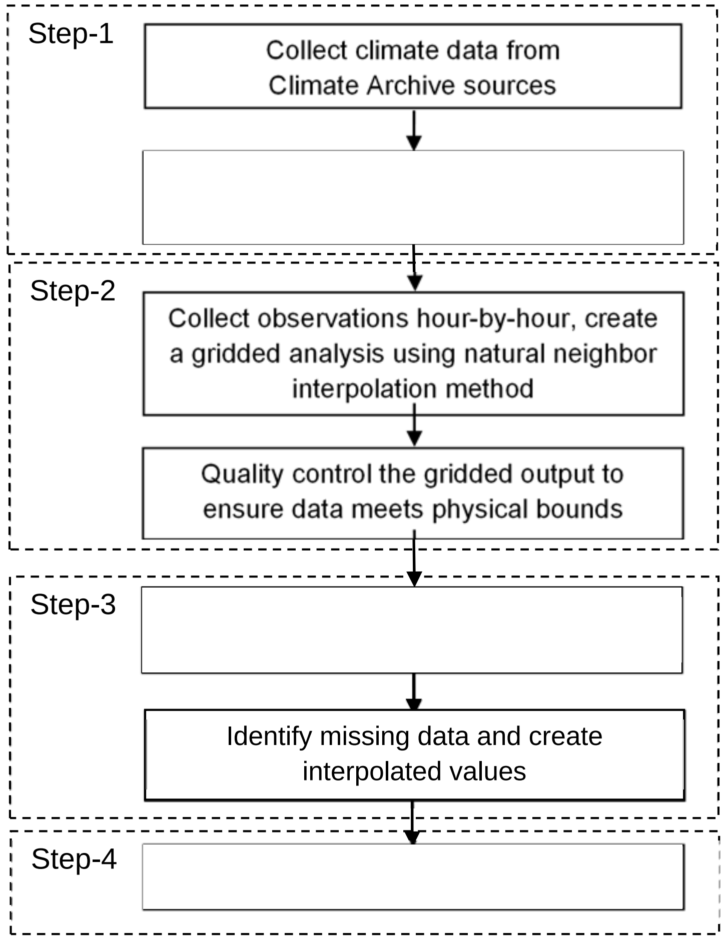


Figure 3

Process for generating historical climate files

The Iowa Environmental Mesonet (IEM) is a data collection project within the Department of Agronomy at Iowa State University at Ames, Iowa. The IEM maintains archives of the ASOS and COOP observation datasets. The IEM archive was expanded to include the geographic area and period of historic time to support the domain of interest for this work by downloading data from available archives found on the Internet. The primary source of these archived datasets was the NCEI. As with any observation dataset, issues of data quality and quantity are of concern.

While the COOP dataset provides a very high quality observation record, the daily time interval presents a challenge for use on hourly time steps. The COOP network also does not record percent sunshine, relative humidity, or wind speed. While the ASOS dataset provides all of the variables needed, it contains errors and gaps of missing observation. Table 2 presents a summary of what the climate data sources contain and how they contribute to variable formulation to build the required MEPDG climate data sets. The ASOS air temperature data give values at the reporting times, but daily extremes may occur between reporting times and may be better captured by the COOP data.

Table 2
Variables required and their data sources

Parameter	ASOS/AWOS	COOP
Reporting Interval	Hourly	Daily
Air Temperature	Value at reporting time	Daily high/low observed
Wind Speed	Value at reporting time	N/A
Relative Humidity	Value at reporting time	N/A
Percent Sunshine	Value at reporting time	N/A
Precipitation	Amount accumulated since last report	Amount accumulated daily

While not exhaustive, some general data quality checks were made to remove any data outside of reasonable physical bounds for Louisiana (i.e., temperature of 150^{o} Fahrenheit, wind speed of 150 mph, or a precipitation amount over 8 in.). Relative humidity and percent sunshine are percent values, so these values were bounded by 0 and 100.

The COOP network has a high spatial density of data and is relatively free of data gaps, so only observations for Louisiana were acquired. On the other hand, the ASOS/AWOS network has a limited number of stations in Louisiana, so observations from neighboring states' ASOS/AWOS stations were acquired to help with the analysis routine. Figure 4 presents sites in the ASOS and COOP observation networks used for this study.

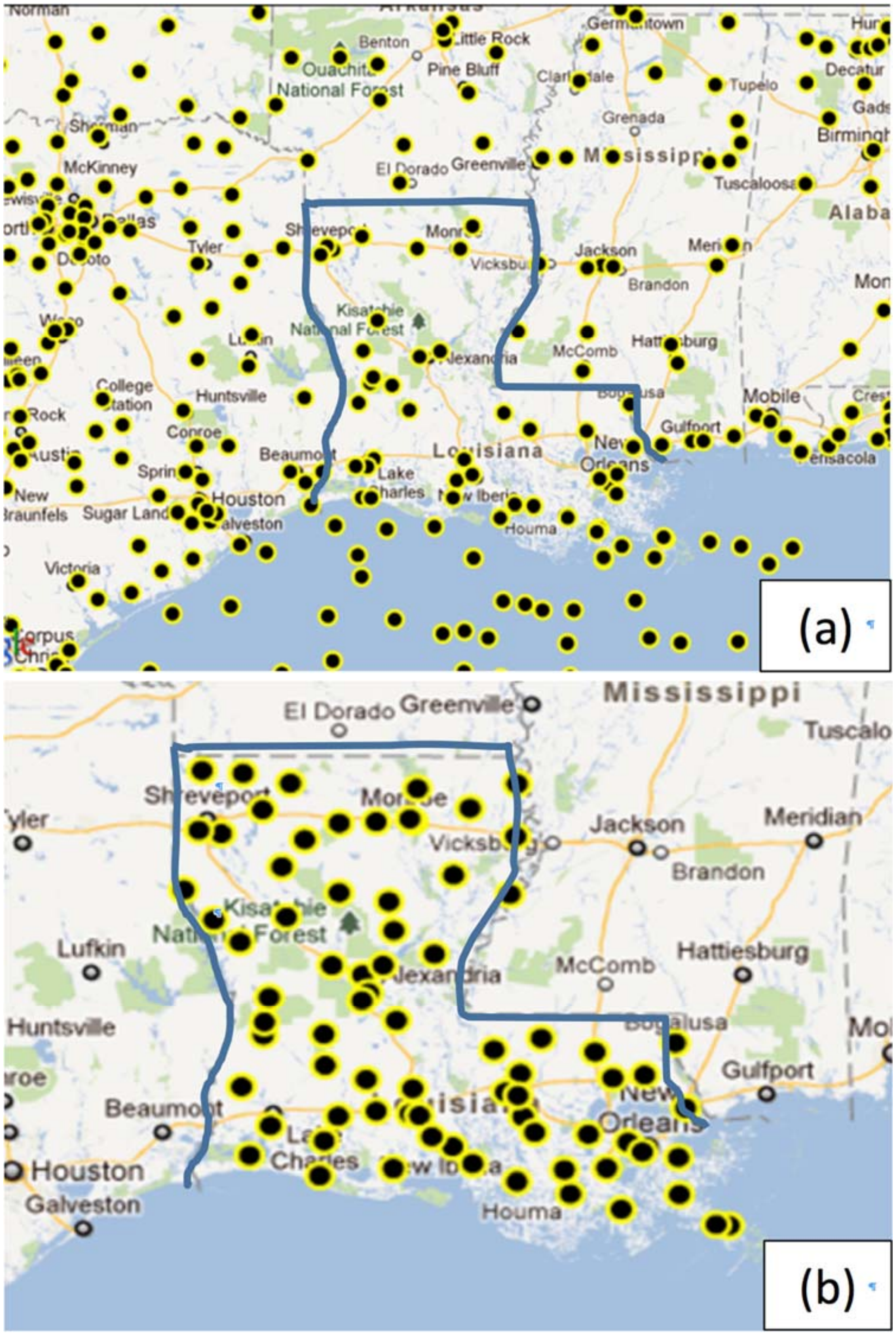


Figure 4

Climate sites (a)ASOS/AWOS sites (b)NWS COOP sites with 1970-2009 data

Step 2: Produce an Hourly and Daily Gridded Data

Since all of the parishes do not have both ASOS and COOP observation points, a gridding technique was utilized to interpolate values spatially. A rectangular grid was constructed covering Louisiana. The grid point spacing was approximately 15 miles and included an exterior buffer of approximately 15 miles. There are generally one to two grid points per parish in the state, as shown in Figure 5.

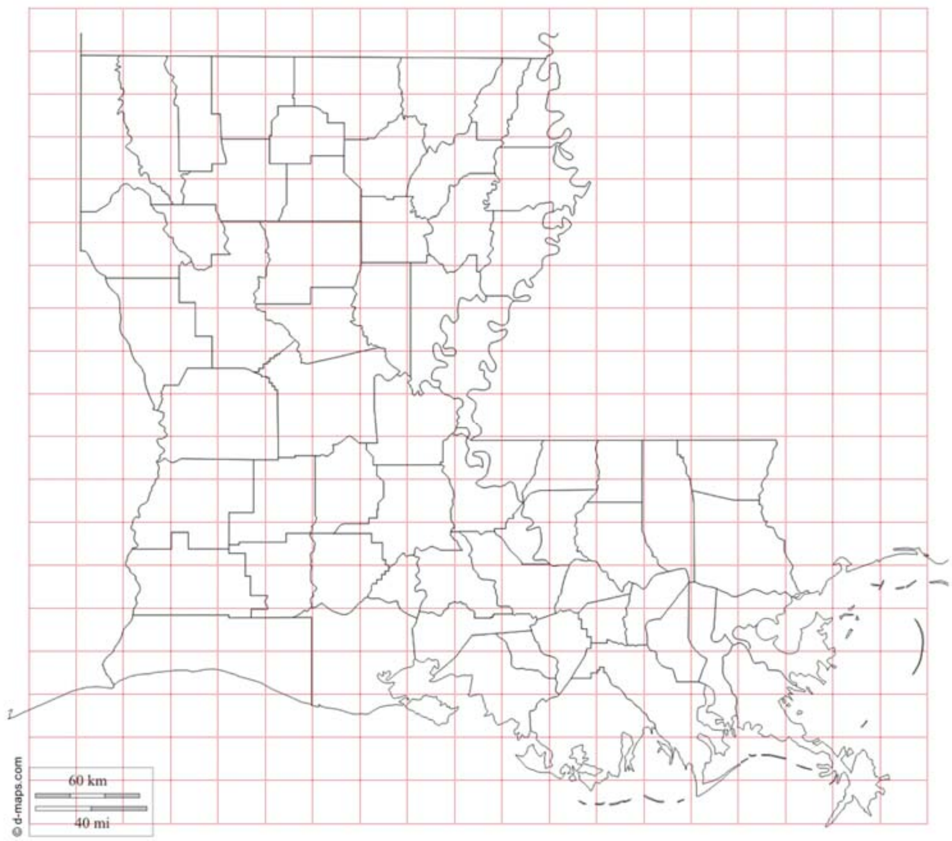


Figure 5
Spatial grid used for interpolated analysis

The gridding procedure employed a natural neighbor interpolation method commonly used in meteorological applications of producing a grid analysis *[1]*. An illustration of this interpolation technique is shown in Figure 6. Each intersection of the grid lines represents a point in space where interpolation was done. The analysis routine works by considering the relative contribution (based on distance and directional density) of observation sites on a prescribed analysis point (or cell) of interest.

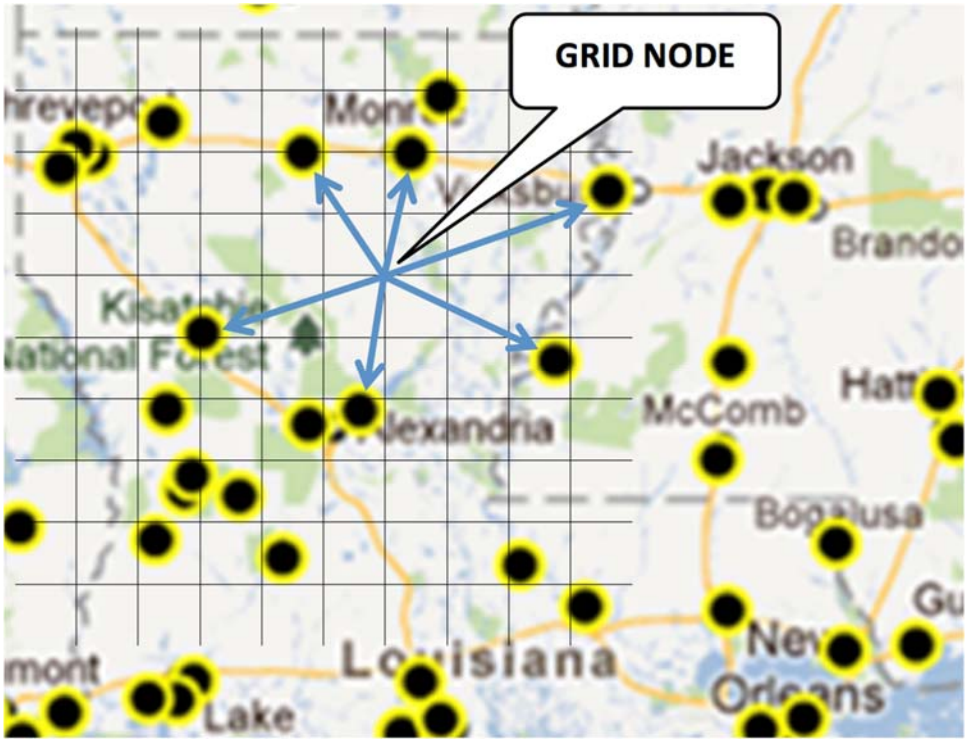


Figure 6
Illustration of natural neighbor interpolation method

For the purposes of this study, code was developed to step through the temporal domain hour by hour and produce an analysis using the natural nearest neighbor interpolation method for the variables of interest. The code required at least four valid neighbor observations for each hour for the routine to work. For grid nodes along the border of the state, ASOS/AWOS data from the adjoining state were used in the interpolation process as needed. If four observations were not found, the analysis was marked as missing (more on this later in the text). With the current archive available to the IEM, this error condition was met approximately 11 times (11 missing hours out of 350,640 hours). During these missing hours, all variables were typically missing.

The COOP data were also gridded on daily time steps. The observation record of COOP sites was of very high quality and little work was necessary to account for incorrect data. The same neighbor interpolation technique was used to generate the daily high temperature, low temperature, and precipitation onto the common data grid. There were no days with less than four observations, so the gridding technique did not produce any missing values. In fact, each day had over 127 observations available.

Step 3: Generate Grid-Point Data Sets and Produce MEPDG Climate Files

With the complete hourly and daily gridded data, code was written to extract the values from the grid for the grid point nearest to the centroid of each parish. While a more sophisticated areal weighting could have been done, it would not have provided more accurate data due to the coarseness of the data supplied and the interpolation technique's tendency to smooth out fine-scale details.

As shown in Table 2, certain climate variables were constructed from a combination of ASOS and COOP archives data. The approach to building grid-point data sets utilized the advantage of high quality COOP observations and the hourly ASOS values. For air temperature and precipitation, the higher quality COOP data were used to adjust the lesser quality hourly ASOS data while maintaining the hourly trend. Figure 7 illustrates an example result of this adjustment. The observed temperature curve is stretched and compressed to match the provided daily high and low temperature.

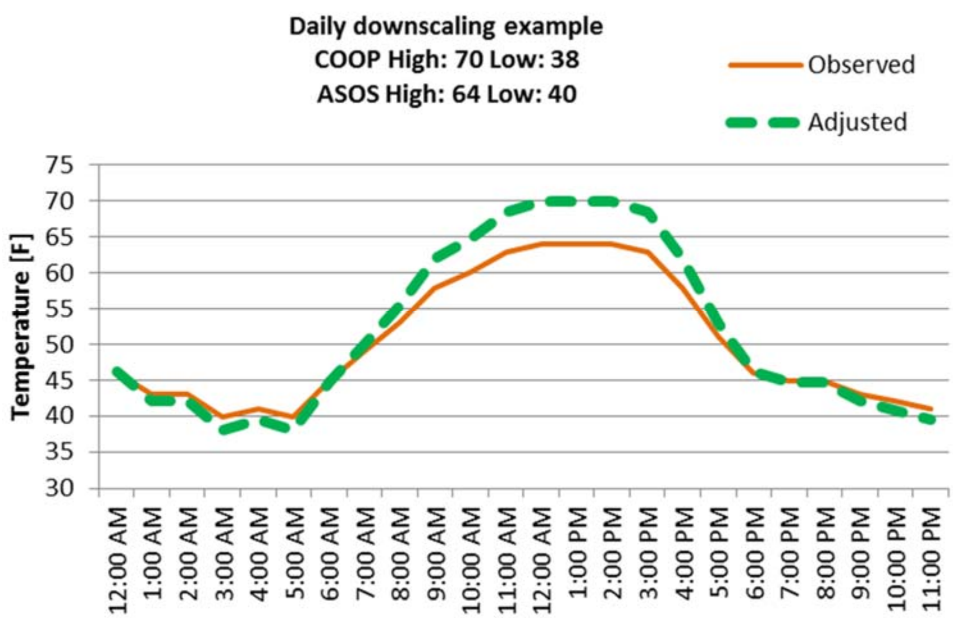


Figure 7

Example of using daily high and low temperature to adjust hourly values

The gridding procedure detailed in Step 2 was not able to produce a gridded analysis for each hour in the 40-year period of interest. Since the hours without data occurred only at isolated and widely spaced locations over time, a simple linear temporal interpolation was done between the hour before and the hour after to create a complete data set. More sophisticated approaches could have been done in place of this linear interpolator, but the suspected accuracy gain was not deemed worth the effort.

The result of this step is a climate data file that can be processed by the MEPDG software. This file has a .hcd suffix and also requires an associated entry in the station.dat file distributed with the MEPDG.

Step 4: Check the Quality of the .hcd File

The .hcd file resulting from Step 3 was processed through an analysis script to ensure it was well formed and did not contain invalid values. The following checks were performed on the file:

1. A set of values was present for each hourly time step between 1970 and 2009. The files were inspected to verify 350,640 lines in the file.
2. The values in the file were checked for any out of bounds values.
   - No percentage values above 100 or below 0.
   - No negative wind speeds or precipitation.
3. For each variable, the maximum and minimum values were examined. Values outside the ranges described below were further examined for possible errors. These numbers were manually inspected for reasonableness.
   - Maximum air temperature should be around 100^{o}F and minimum around 0^{o}F.
   - Peak wind speeds shouldn't be much higher than 50-70 mph (typical value of a severe thunderstorm). Some sites may have hurricane data included in them, so locally higher values may happen.
   - Maximum precipitation values should be around 2-3 in..
4. Monthly summaries were generated and manually inspected for any suspicious values.

If errors were found, the data were investigated and the procedure was restarted at Step 2 to correct any errors. The products of this four-step process for building historic climate files are one .hcd file per parish (64 files) and the station.dat file the MEPDG software uses to reference the .hcd files. The last quality control check was using each parish climate file as an MEPDG input file and ensuring the MEPDG analysis completed without errors.

Developing Future Climate Files

The current MEPDG process uses historic climate data as the input for predicting future pavement performance (distress). While this is better climate input compared to previous pavement design processes, it lacks the recognition that the climate of the past 20 years should be adjusted based on scientifically known climate change trends. Under this study, the research team provided the Louisiana Department of Transportation and Development (DOTD) a list of options for preparing future climate files. The basic question posed to the DOTD's Project Review Committee was, "What type of data do you want to use for performing pavement analysis?" The group directed the research team to prepare (1) future (adjusted historic climate), (2) random (adjusted random historic climate), and (3) extreme (adjusted biased historic climate) climate scenarios.

Establishing a Global/Regional Climate Model

Developing a future climate scenario for assessing impacts of climate change requires the use of a global climate model to create the climate conditions that are consistent with the trend of rising greenhouse gas concentrations in the earth's atmosphere. The global climate models provide coarse-resolution results (e.g., one grid point for every 35,000 square miles), so a method for refining the spatial distribution of the global climate model results to specific locations within Louisiana was required. Two methods for refined spatial distribution are typically used: statistical downscaling and dynamical downscaling. Downscaling is performed by a regional climate model imbedded into a global model.

The second method, dynamical downscaling, is widely recognized as providing results that are physically consistent with the results produced by the global model, although it is more computationally intense to create the results. Dynamical downscaling has been used for assessing the impact of climate change on wind speed, solar radiation, streamflow in the Upper Mississippi River Basin, summertime daily maximum temperatures, crop production, flow and water quality in the Upper Mississippi River Basin, precipitation intensity, extreme cold season synoptic precipitation events, subsurface tile drainage in Iowa, and pavement performance *[2 - 12]*.

The global climate model of the Hadley Centre in the UK (known as the HadCM3 model) and the dynamical downscaling method that uses the regional climate model HRM3 were selected for this study. A similar global/regional model combination of HadCM2 and RegCM2 was used in the above nine studies. The RegCM2 domain regional climate model used for this study is shown in Figure 8. Four global model nodes bound the area of Louisiana and over 40 regional model nodes are within the boundaries of the state. Figure 9 shows the regional model nodes used for the study.

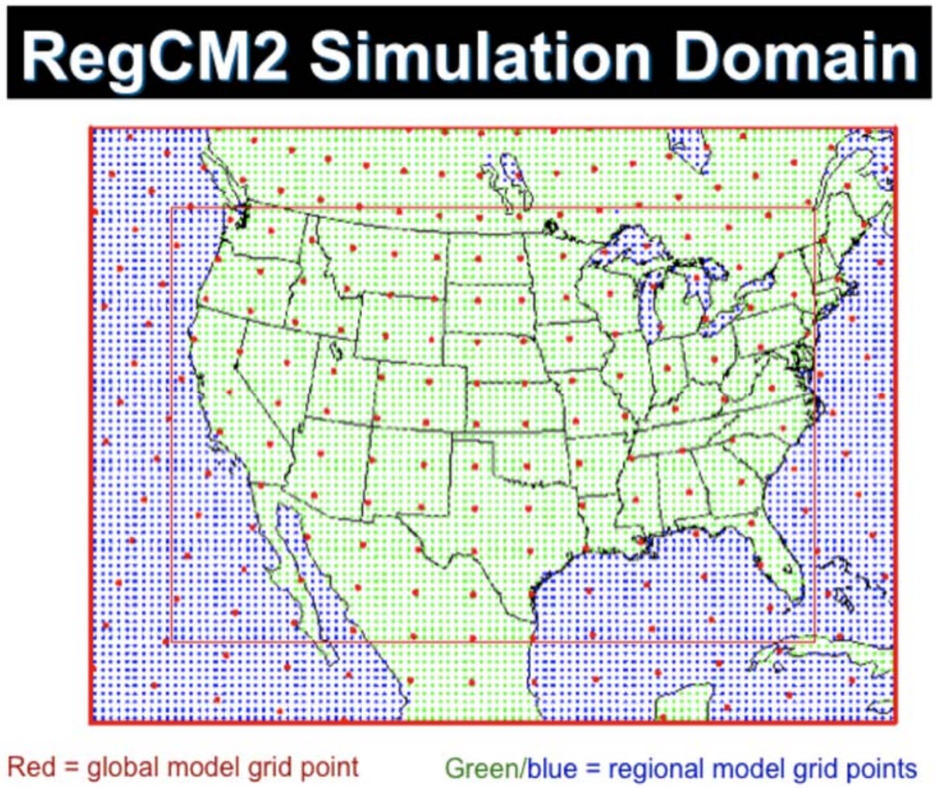


Figure 8

Climate model domain grid point locations for global and regional models

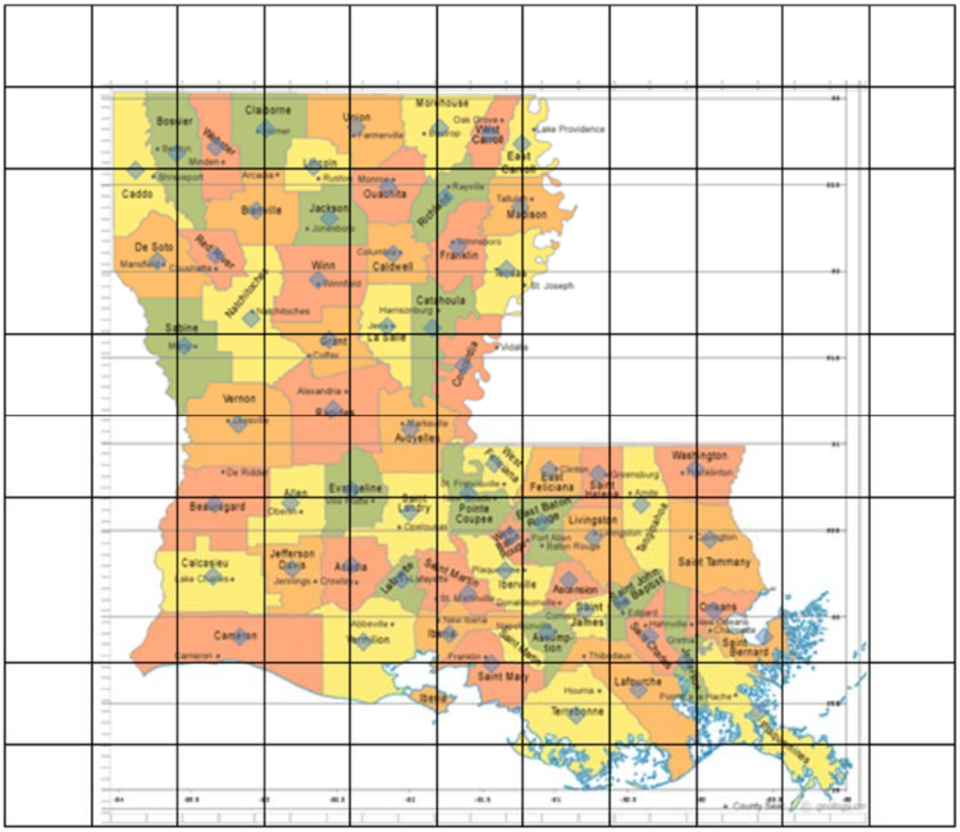


Figure 9
Louisiana global/regional climate model grid

Building Contemporary and Future Climates

The basic weather input to the MEPDG pavement model is a multi-year time sequence of hourly weather variables for a particular location. When the pavement model is run using past climate as input for a particular location, the meteorological file contains hourly temperatures, precipitation, and others influenced by occurrences of El Niños, La Niñas, and hurricanes. These irregular, but important, regional climate influences exist and evolve in response to changes in sea-surface temperatures that also slowly change in time. At a given location such as New Orleans, Louisiana, the hourly progression of temperatures is strongly influenced by these “remote” conditions.

Global climate models simulating future climates do not simulate future year-to-year changes in sea-surface temperatures and therefore do not produce plausible future El Niños and La Niñas (ENSO conditions). Large-scale conditions leading to hurricanes are simulated with global climate models, but the hurricanes themselves are not produced by such models. Therefore, simply using global climate model output to represent future weather sequences would miss important and known influences on climate variability. There are a couple of ways to address this dilemma. The simplest method is to start by using a global model to create two proxy climates: a contemporary climate representing 30 years of history (1971-2000) and the future scenario climate representing 2041-2070. The global/regional models for building the contemporary and future climates are shown in Figure 10. The global/regional climate model used to generate these is a “first principles” model based on real, physical processes. This global model of the atmosphere is given an accurate amount of solar radiation at the top of the atmosphere and greenhouse gas concentration in the atmosphere representing each 3-minute time step for the 30-year period. As a result, the region simulation (i.e., continental U.S.) has the basic seasonal and daily cycles of weather variables for each longitude, latitude, and altitude point within the model.

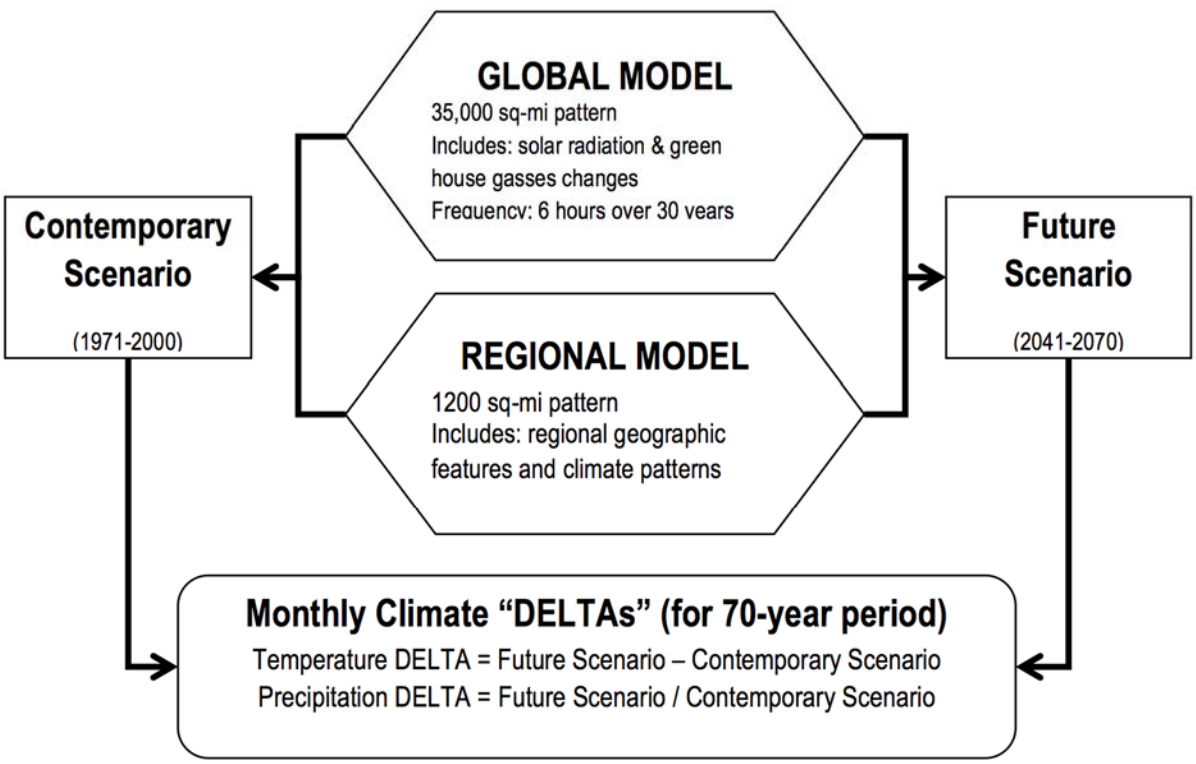


Figure 10

Process of developing temperature and precipitation deltas

The contemporary climate developed by the combined global/regional model differs somewhat from the actual historical records for 1971-2000 for several reasons. First, the land surface in the regional climate model includes major topographical features such as mountains and major water bodies, but it might not include the influence of a small lake since it does not specify conditions smaller than about one fourth the size of a typical parish. Also, vegetation does not green-up naturally in the model but is changed abruptly in the spring. Furthermore, effects of clouds are not represented accurately because they can occur on many spatial scales and have physical properties that are too small to be fully represented in the regional model. As a result of the approximations used to account for these deficiencies, the regional model produces a contemporary climate that has realistic seasonal and daily cycles but may have a systematic bias; that is, the regional model may always be 2-4 degrees Fahrenheit too cool or too warm for a particular location in a particular month when compared with the recorded historical climate.

The future scenario climate uses the exact same global model with the exact same land surface (e.g., cities of same size, same agricultural regions, etc.) and same solar radiation at the model top used for the "contemporary climate." The only difference is the global model used to create the boundary conditions for the regional model has a different amount of greenhouse gas (carbon dioxide and methane) in the atmosphere than the contemporary climate model. The result is generally slightly higher temperatures in the lower atmosphere with subsequent changes in evaporation, cloudiness, etc. The future scenario climate produced by this procedure will also have similar biases as those described for the contemporary climate. However, since the same global climate model is used for both, their biases should be similar. When the contemporary climate values were subtracted from future scenario climate values (for the same month and time of day), the biases were eliminated or much reduced. The difference (future climate minus contemporary climate) for each grid point and each month produced the "climate deltas."

Building Future Climate Files Using Model Deltas

The climate deltas represent the expected change in future climate due only to the impact of changes in the influence of solar radiation due to the changes in greenhouse gas concentrations between the future period (2041-2070) and the contemporary period (1971-2000). They do not represent changes in frequency or intensity of El Niño or La Niña events. To simulate the influence of such events, the monthly climate deltas were added to the observed historical record of the period 1970-2009. In this way, extreme events of the historical record were represented in the future climate constructed for use in the MEPDG pavement performance analysis. The climate deltas were created separately for each regional grid point in the state for each month of the year. A diagram of the process for creating the climate deltas is shown in Figure 10. The 70-year deltas were reduced to an annual rate so they could be applied to the 40-year historic climate data.

Temperature deltas were computed as the difference of the model's future climate 30-year average value minus the model's contemporary climate 30-year average value. See Figure 11 for one example of the monthly temperature comparison for one regional grid point. Note that the delta for each month was positive. For precipitation deltas, the customary procedure used the ratio of (F-C)/C (future scenario climate value minus contemporary climate value divided by contemporary climate value) to define the delta. Using a ratio delta for precipitation ensured that there would be no negative precipitation values in the future climate files. Individual hourly precipitation values would be adjusted by multiplying by the ratio, not subtracting by the value. See Figure 12 for an example of monthly precipitation comparison for one regional grid point. When the future value was lower than the contemporary value, the ratio delta was expressed as a negative ratio. This produces the future scenario 70-year monthly climate deltas due to climate change.

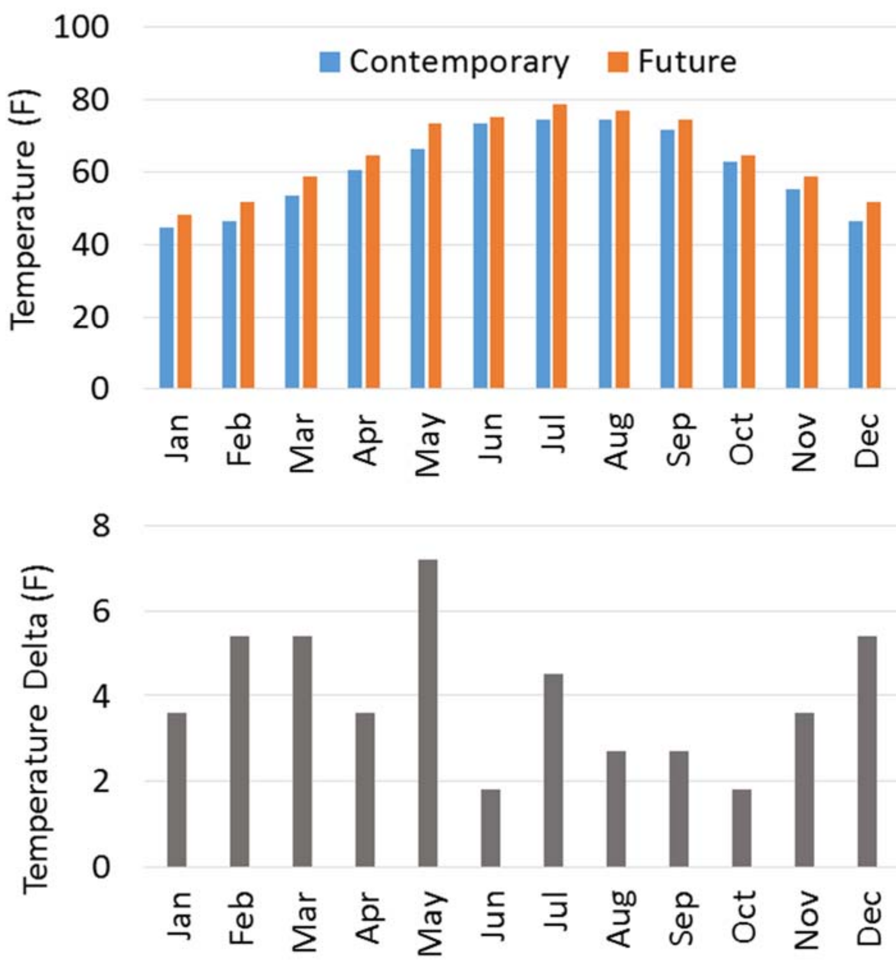


Figure 11

Monthly average and future temperatures for one regional grid point

bottom bar chart presents 70-year temperature deltas

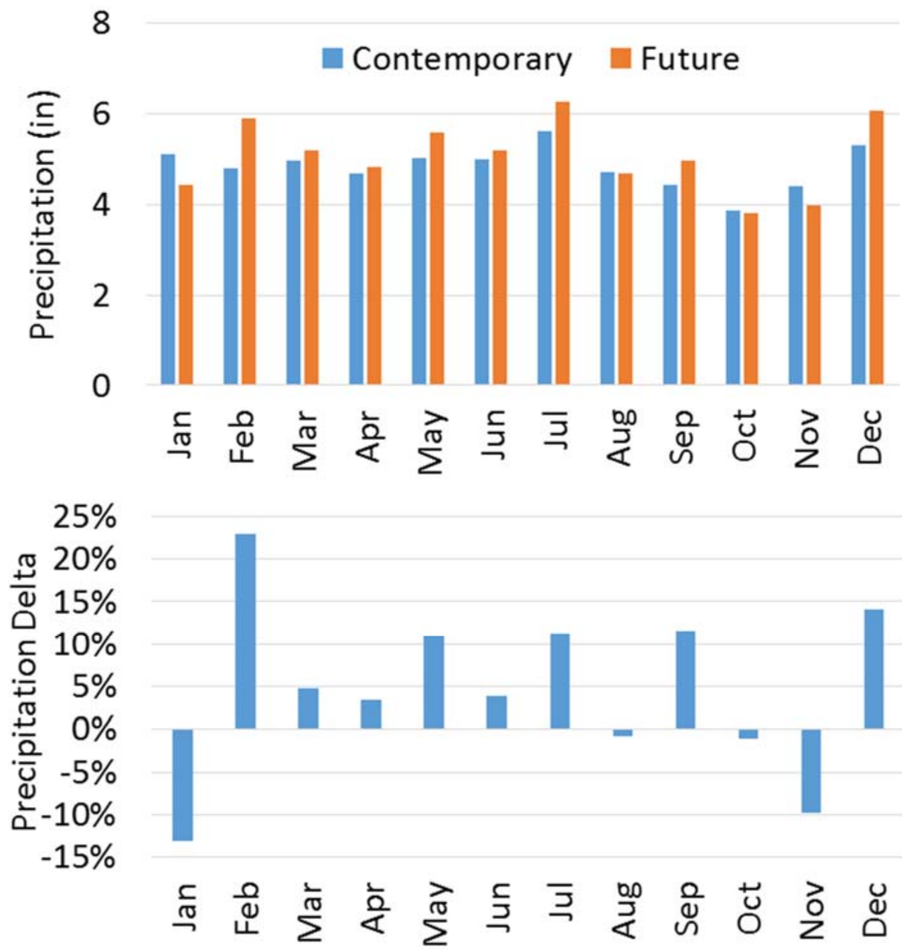


Figure 12

Monthly contemporary and future precipitation for one regional grid point

bottom bar chart presents 70-year precipitation percentage deltas

Steps for Building Future Climate Data

The sequence of building future climate data was performed in the three steps illustrated in Figure 13. Step one determined the 40-year linear trend of the historic climate (temperature or precipitation) from the 1970 to 2009 data, as shown in Figure 13a. Note, this is a hypothetical example, so the values of the y-axis are generic and do not represent a specific climate feature. The significant differences of the historic climate from this linear trend are the interannual variability due to conditions such as El Niño, which were quantified by subtracting the trend line values from the historic values for each year. Step two determined the trend for the future 40-year period by applying the climate deltas to the historic climate. The trend line for 2010-2050 was then tied to the end of the trend from 1970-2009 at year 2010. Step three added the interannual variability, obtained from the difference between the historic trend line and historic climate, to the period from 2010-2050. Note that the interannual variability of the historic climate pattern from the period 1970-2009 was reproduced in the future 2010-2050 period but adjusted along a slightly different (increased) slope created by the monthly climate deltas (see Figure 13b).

As previously mentioned, the creation of future precipitation conditions is done slightly differently than those for temperature. The precipitation climate delta is a ratio of the monthly future scenario climate value to the contemporary climate value. The monthly delta may be positive or negative. This monthly value is applied linearly on a daily basis to adjust the observed data into the future. A consequence of this procedure is that the distribution of wet and dry days remains the same in the future as was observed in the historic record (1970-2009). When it rains, it simply rains more (or less) as dictated by whether the precipitation delta is greater than or less than 100%.

A future climate file was developed for each parish by superimposing the monthly global/regional delta(s) at the regional grid points relative to each parish location into the 40-year historic file for the parish. This process generated a unique 40-year future climate file for each parish.

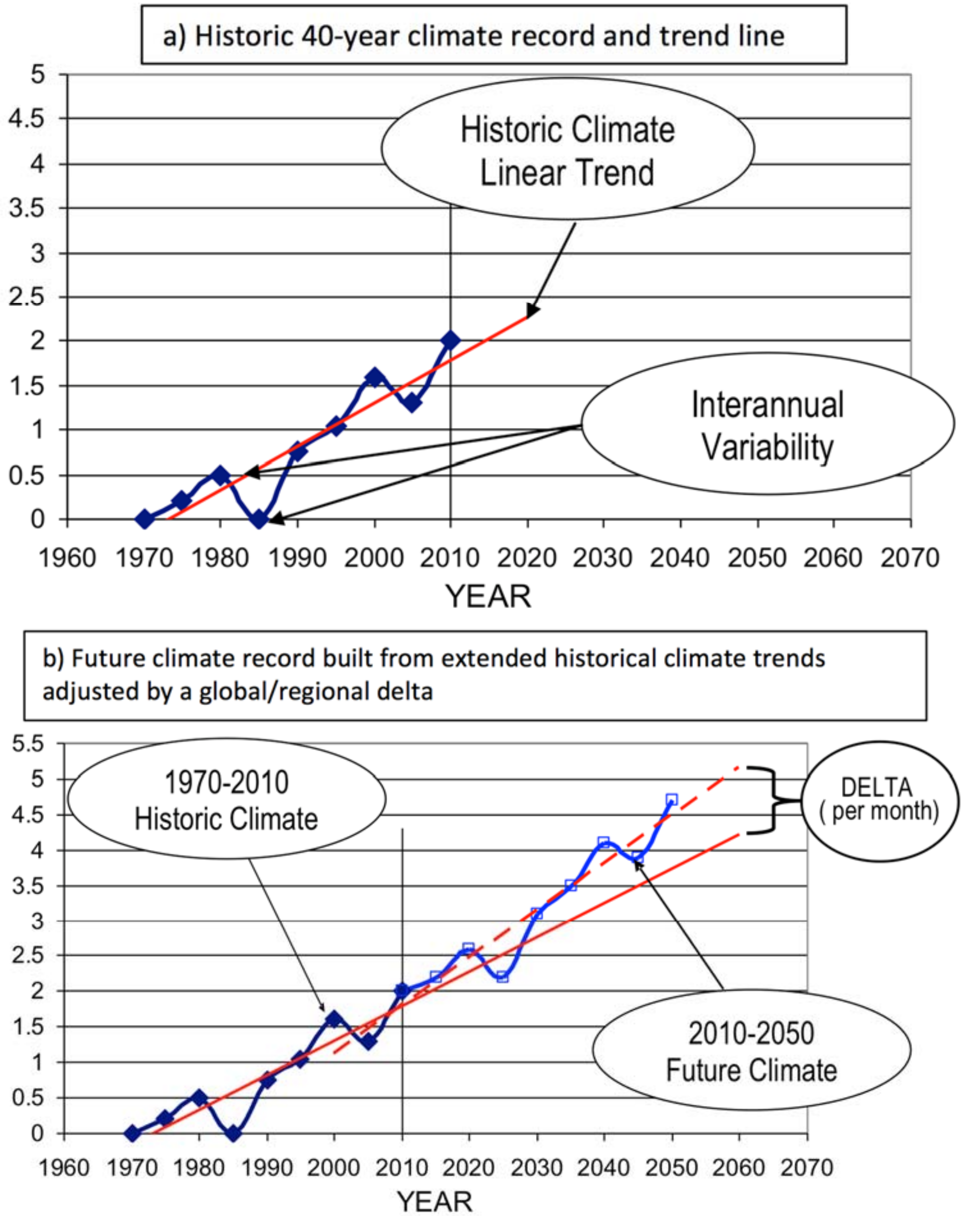


Figure 13
Illustration of building a virtual climate record

Developing Random Climate Files

The second set of future climate files is based on the concept that the extreme events and cycles observed in historic climate data may not occur in the same sequence in the future. The intent of this effort is to randomize the sequence of historic climate data as the initial step of producing future climate files. The random climate file maintains all the extreme historic climate events, but does so in a random pattern. These random climate files provide the pavement design engineer with unbiased input files for examining predicted future pavement performance.

The initial approach for developing random climate files was to separate each historic climate file data into annual subsets of data and then re-sort the 40 subsets to create a random 40-year climate. After discussions with the DOTD, the plan was revised to separate the historic climate file into multi-year climate cycles that accounted for high/low temperature patterns over every three to five years. The scale of this effort was reduced to one parish file in each of the nine climate zones in Louisiana. Figure 14 is a map of the Louisiana climate zones and the randomly selected parish in each zone.

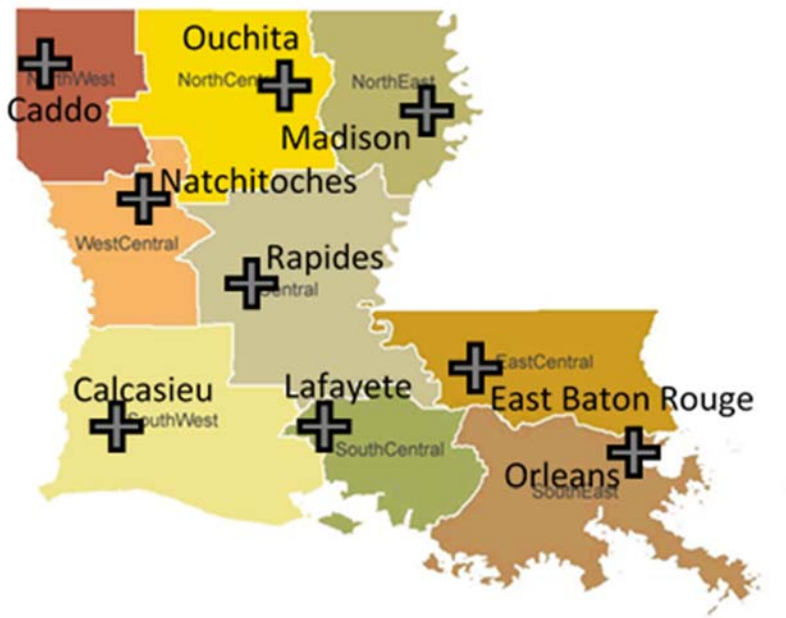


Figure 14
Louisiana climate zones and selected parishes

Identification of Climate Cycles for Temperature

This section describes the process for identifying the multi-year cycles of climate over the 40 years of historic data. The nine selected parish historic climate files were used as MEPDG input and the resulting MEPDG climate output data were examined. The 40-year climate history for Louisiana was divided into cycles based on high temperature using two parameters: (1) peak years based on the number of hours per month above 95°F, and (2) peak years based on maximum monthly high temperature. The monthly air temperature history graphs for Caddo Parish are shown in Figure 15. Below each graph is a row listing the selected peak years.

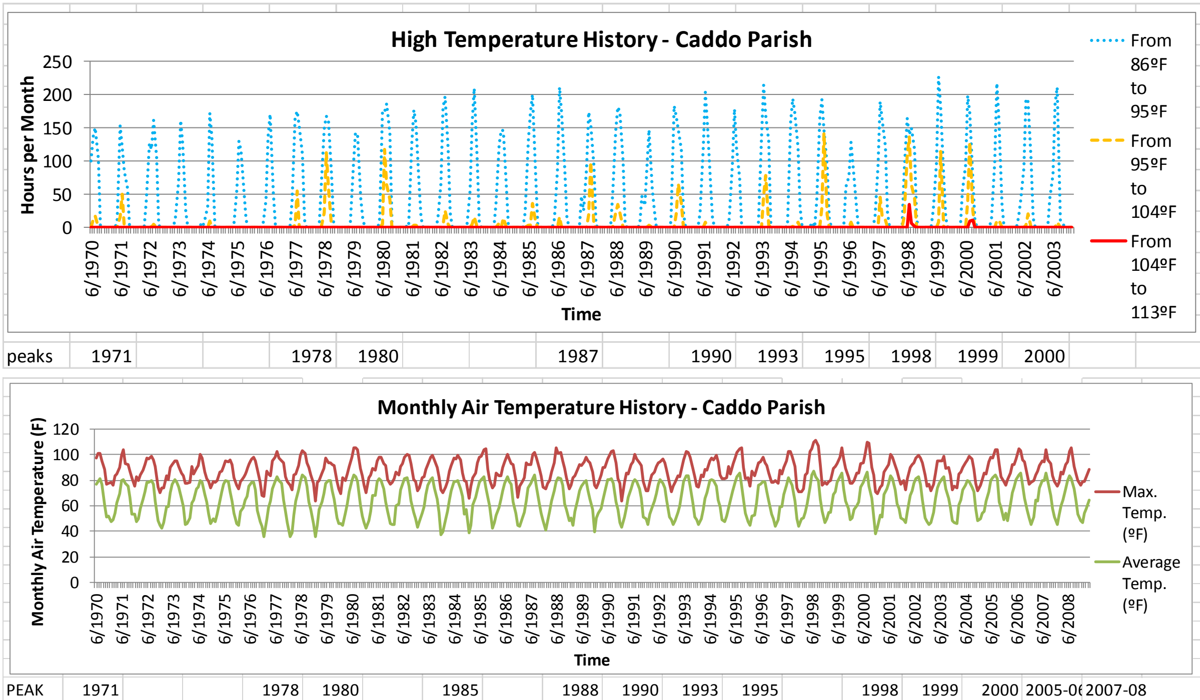


Figure 15

Identifying maximum temperature events for Caddo Parish

A summary of the peak years for all nine climate zones is shown in Figure16. For example, all nine climate zones showed a peak in 1980 and 2000. As expected, there was a reasonable correlation between monthly hour peaks and monthly high temperature peaks. The MEPDG software truncates the hours per month data, so peak years beyond 2004 were not available. Below the x-axis, the figure also shows the climate cycles derived from the peak temperatures. The length of each cycle was controlled by two rules: (1) a cycle is no less than four years, and (2) a cycle begins January 1 and ends December 31. The selected temperature cycles are listed in Table 3.

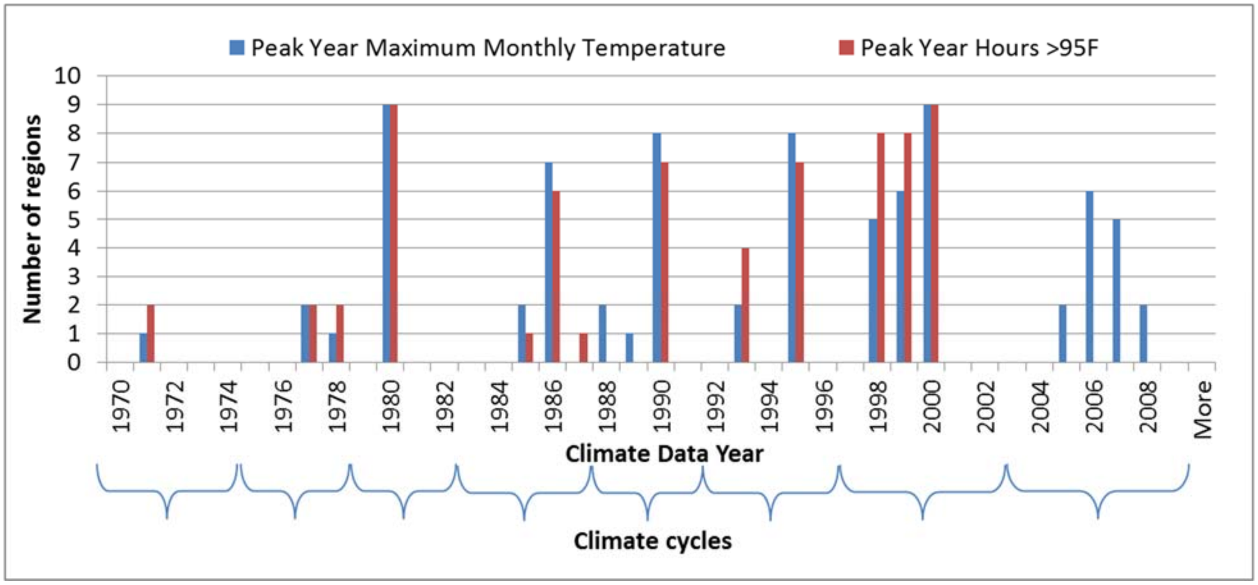


Figure 16

Developing climate cycles based on maximum temperature events

Table 3

Climate cycles for 1970-2009 based on high temperature

Climate Cycles	Number of Years	Cycle ID
1970-1974	5	A
1975-1978	4	B
1979-1982	4	C
1983-1987	5	D
1988-1991	4	E
1992-1996	5	F
1997-2002	6	G
2003-2009	7	H

Random Sort of Climate Cycles

New 40-year random climate files were generated by randomly sorting the eight identified cycles. A simple spreadsheet random number generator was used to randomly sort the cycle identifications A through H. The baseline (historic) and re-sorted (random) 40-year data sets for one climate zone were compared to confirm that the process for re-grouping the climate cycles was successful. The distributions of the hourly temperatures matched, as shown in Figure 17. A random climate file was generated for each climate zone using the same cycle increments and random sequence.

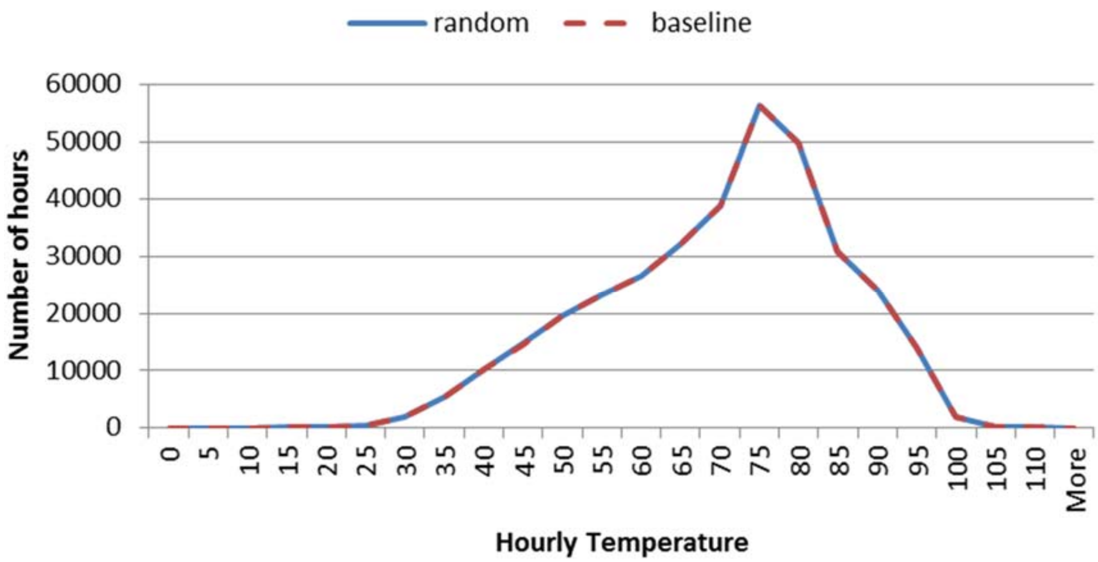


Figure 17
Comparison of historic and randomly re-sorted hourly climate data

A critical step in this process was matching the hourly climate data from the end of one cycle to the hourly climate beginning the next cycle. It is important that this period contain reasonable changes in temperature to avoid shocks to the data sequence that may create invalid pavement predictions. The methodology used was to implement a smoother (transition algorithm) between the two periods that slowly adjusted the data to create a smoother transition. The smoother increased in intensity the closer it got to midnight on January 1. An example of this smoother is presented in Figure 18. The merged cycles produced an approximate 25 degree change in temperature over one hour. The smoother relaxes this change to occur over a 12 hour period.

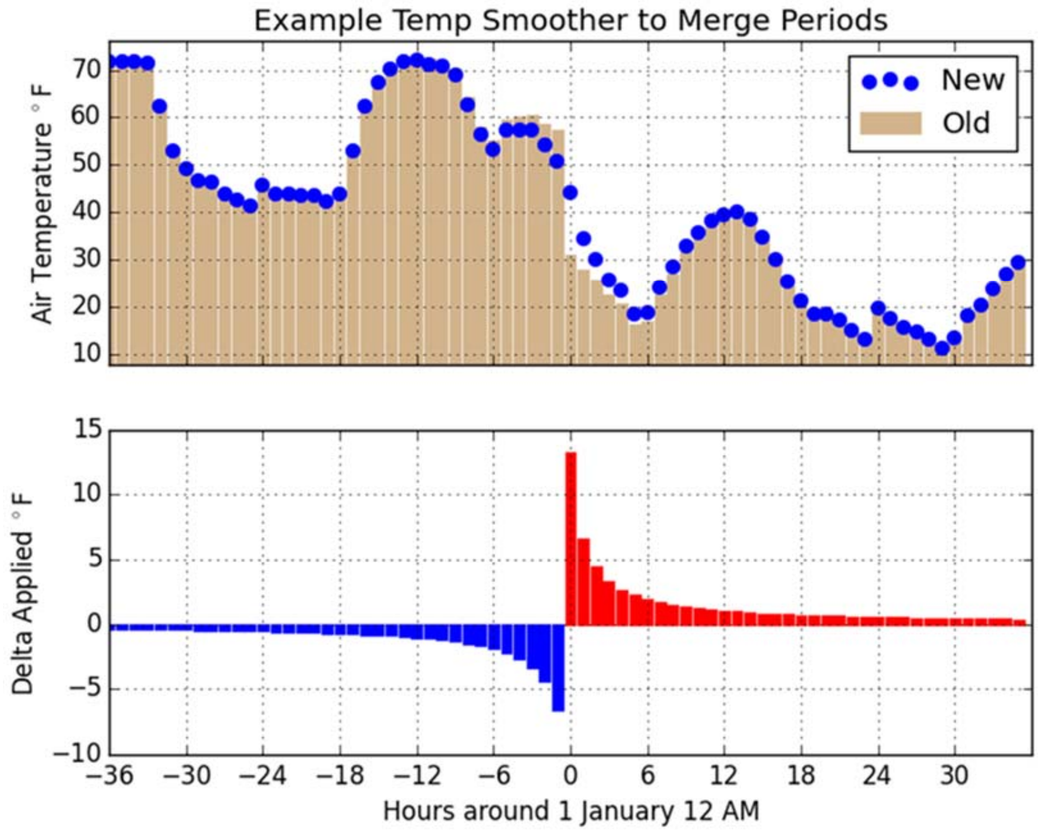


Figure 18
Example of smoother method to merge climate cycles

The development of future random files was accomplished by combining the cycles as selected above in the order specified by the random selection. This combination required the smoother algorithm to ensure that no drastic changes occurred between the cycles at midnight on January 1. The resulting .hcd files were quality controlled with the same software and techniques used for the historical files.

Developing Extreme Climate Files

DOTD was interested in the influence of extreme climate sequences on the predicted pavement performance. This effort defines extreme climate based on temperature and precipitation. This section of the report describes the process for developing extreme climate sequences for temperature and precipitation. Climate cycles based on high temperature patterns were used to develop new 40-year climate files as previously discussed. These same high temperature patterns were used to develop a high intensity high temperature sequence (HIT) and a low intensity high temperature sequence (LIT).

Temperature Extremes

To identify temperature extremes, data for each climate cycle were compared. This analysis was done for Caddo Parish with the highest temperature extremes and the resulting sequence of cycles was used for the nine climate zones. The analysis included:

a) number of months with a maximum monthly temperature above 90°F
b) number of months with a maximum monthly temperature above 95°F
c) number of hours with a temperature above 95°F

Table 4 shows the combination of the high temperature extremes used to select the HIT ranking between cycles. For example, the climate cycle for 1997-2002 had the highest ranking in all three categories and was ranked the highest HIT cycle. Cycle 1970-1974 had the lowest number of hours with a temperature above 95°F and was ranked the lowest. Each cycle was placed in the ranked sequence based on the combination of the three criteria.

Table 4
Caddo Parish high temperature data used to rank climate cycles

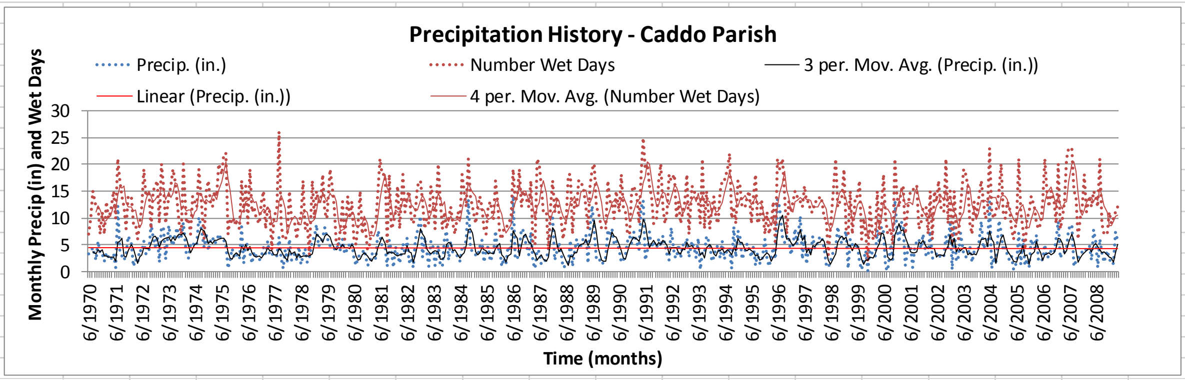
CLIMATE CYCLES	CYCLE YEARS	ADJ YEARS		BASED ON >90F CYCLE MONTHS	BASED ON >90F mon/yr	BASED ON >95F CYCLE MONTHS	BASED ON >95F mon/yr	BASED ON >95F CYCLE HOURS	BASED ON >95F hr/yr	HIGH TEMP CYCLE	HIGH TEMP RANK	
1970-1974	5	4	1971-1974	22	5.50	11	2.75	87	22	A	8	lowest hours
1975-1978	4	4	1975-1978	20	5.00	11	2.75	258	65	B	6	
1979-1982	4	4	1979-1982	21	5.25	11	2.75	275	69	C	3	high hours
1983-1987	5	5	1983-1987	26	5.20	16	3.20	232	46	D	4	high months
1988-1991	4	4	1988-1991	23	5.75	10	2.50	216	54	E	7	lowest months
1992-1996	5	5	1992-1996	25	5.00	13	2.60	343	69	F	5	
1997-2002	6	6	1997-2002	32	5.33	19	3.17	873	146	G	1	highest hours and months
2003-2009	7	6	2003-2008	32	5.33	18	3.00	na		H	2	second highest months

Precipitation Extremes

The process used to develop extreme climate files based on precipitation was similar to the process used for temperature files. One additional step compared the statewide HIP sequence to climate zone-by-climate zone HIP sequences because precipitation patterns were not as uniform between climate zones as the temperature patterns. The following steps were used to identify precipitation cycles, high intensity precipitation sequence (HIP), and low intensity precipitation sequence (LIP):

1. Generate a graph of the monthly precipitation and wet-days data from MEPDG output files.
2. Smooth the monthly data with moving average trends.

3. Identify the years with high precipitation, high wet-days, and low precipitation (dry). The results of steps 1-3 for Caddo Parish are shown in Figure 19.
4. Assemble the high precipitation, high wet-days, and dry data from all nine parishes into histograms (see Figure 20).
5. Identify precipitation cycles using dry cycles as beginning points and keep each cycle size between three and seven years (see Table 5).
6. Compute the precipitation and wet-days intensity in each cycle.
7. Sequence the cycles for worst-case condition.
8. Compute the average precipitation per month for each cycle for all nine zones (Table 6) and rank each zone's cycles (see Table 7).
9. Compare the statewide sequence (Step 7) to the zone-by-zone sequence (Step 8).
10. Adjust the worst-case sequence to meet the majority of climate zones.



precip peak	1974	1979		1984	1986		1991		1996	2001		2007
wet peak	1974		1981	1984	1987		1991	1994	1996	2001		2007
precip low		1977	1980		1985	1990		1995		1999	2005	

Figure 19

Selecting precipitation cycles using annual dry events

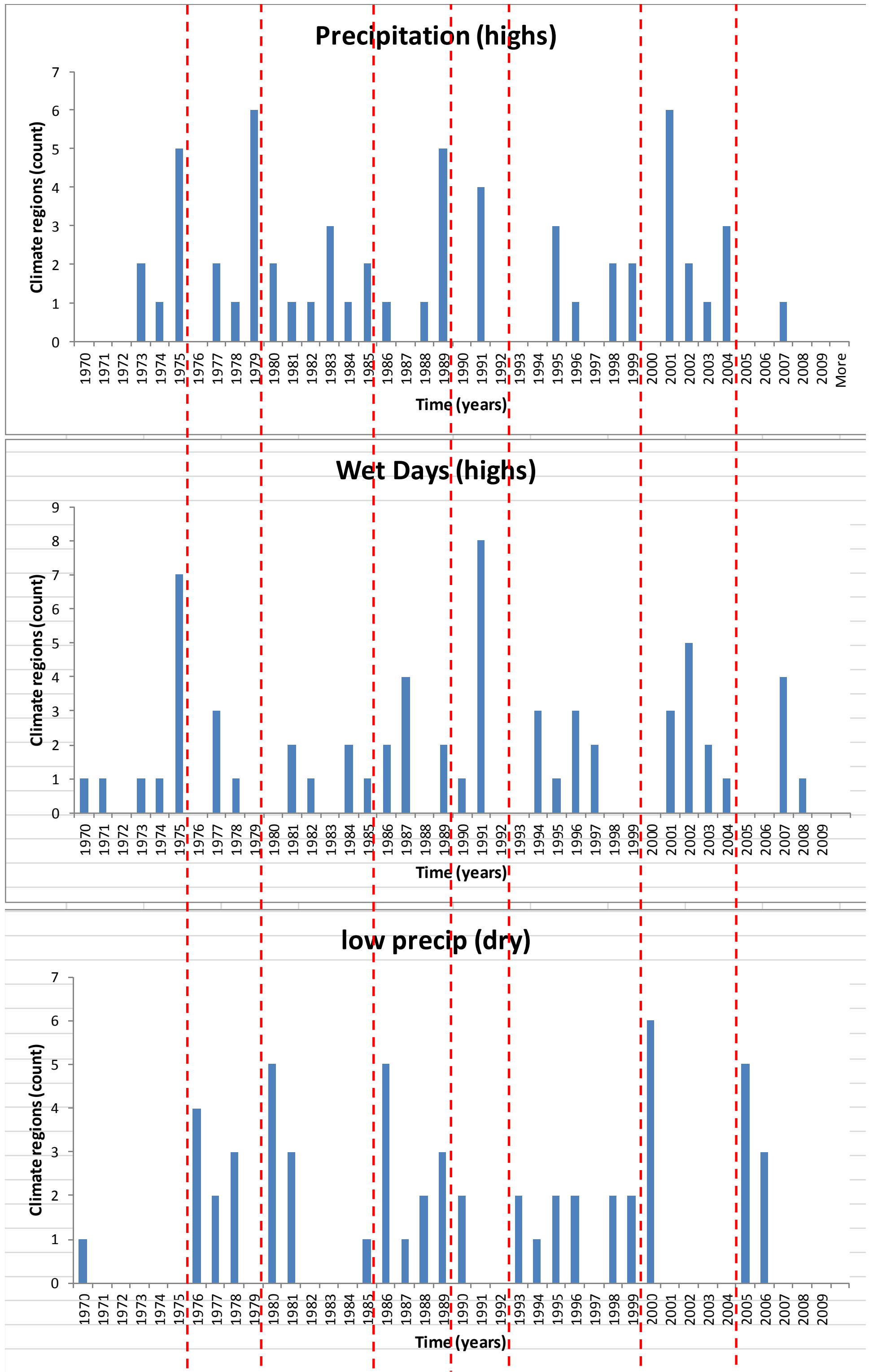


Figure 20

Selecting precipitation cycles using annual dry events

Table 5
Selected precipitation cycles

Cycle	Years
A	1970-1975
B	1976-1979
C	1980-1985
D	1986-1989
E	1990-1992
F	1993-1999
G	2000-2004
H	2005-2009

Table 6
Statewide and zone-by-zone precipitation

		Statewide	Caddo	Ouachita	Madison	Natchitoc	Rapides	E Baton Rg	Calcasieu	Lafayette	Orleans
PRECIP CYCLE		events/yr	precip/mo	precip/mo	precip/mo	precip/mo	precip/mo	precip/mo	precip/mo	precip/mo	precip/mo
A	1970-1975	3.17	4.76	4.86	5.37	4.67	5.28	5.48	4.84	5.34	5.38
B	1976-1979	3.25	4.02	4.31	4.58	4.20	5.00	5.12	4.52	5.16	5.34
C	1980-1985	2.67	4.01	4.57	4.92	4.54	5.14	5.09	4.71	4.76	5.39
D	1986-1989	3.75	4.29	4.50	4.33	4.87	4.71	5.57	4.94	4.76	4.85
E	1990-1992	4.33	5.25	5.39	5.59	5.15	5.33	5.85	5.25	5.66	6.54
F	1993-1999	2.43	4.37	4.35	4.46	4.59	4.97	5.08	4.70	5.22	4.93
G	2000-2004	4.60	4.79	5.06	4.79	4.89	5.20	4.84	5.51	5.36	5.16
H	2005-2009	1.20	3.77	4.04	4.30	4.05	4.45	4.36	4.53	4.42	4.86

Table 7
Statewide and zone-by-zone precipitation rankings

STATEWIDE	Parish by Parish worst case based on cycles A-H (precip/mo)									final sequence
(events/yr)	Caddo	Ouachita	Madison	Natchoto	Rapides	E Baton R	Calcasieu	Lafayette	Orleans	WORST CASE
G	E	E	E	E	E	E	G	E	E	E
E	G	G	A	G	A	D	E	G	C	G
D	A	A	C	D	G	A	D	A	A	A
B	F	C	G	A	C	B	A	F	B	C
A	D	D	B	F	B	C	C	B	G	D
C	B	F	F	C	F	F	F	C	F	B
F	C	B	D	B	D	G	H	D	H	F
H	H	H	H	H	H	H	B	H	D	H

Comparing Temperature and Precipitation Cycles

The temperature and precipitation cycles did not match. Figure 21 shows that the high temperature years often followed the low precipitation years. In general terms, the temperature cycles are offset from the precipitation cycles by half the cycle length. Table 8 shows a direct comparison of temperature and precipitation cycles. The LIT and LIP sequences are a simple reversal of the HIT and HIP sequences.

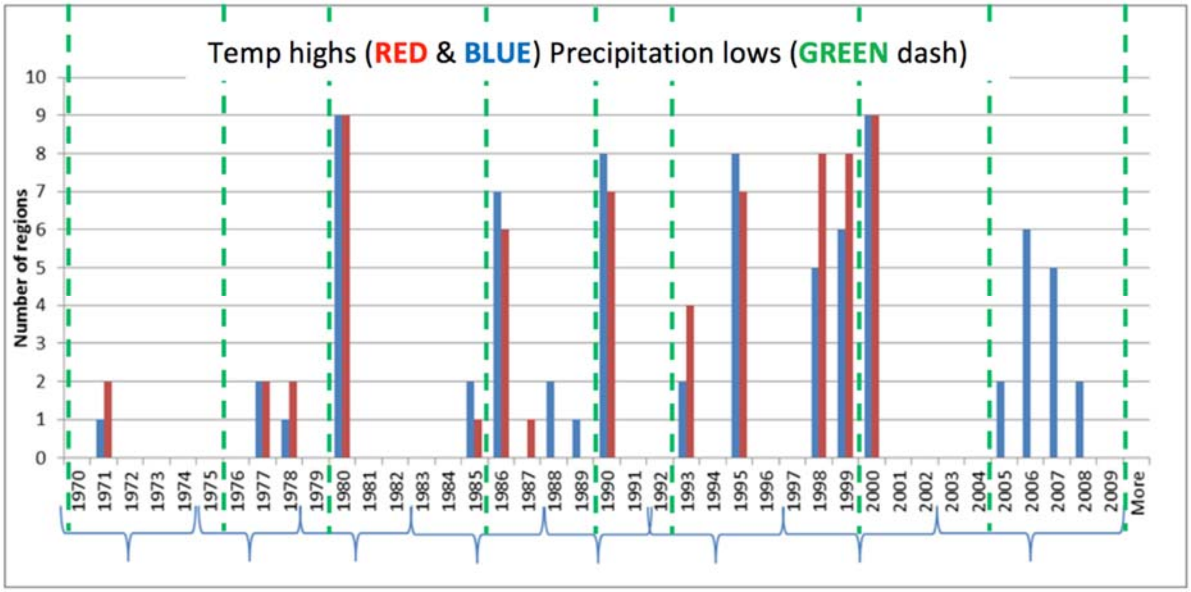


Figure 21
Comparison of temperature highs and precipitation lows

Table 8
Summary of temperature and precipitation cycles and extreme sequences

Temperature				Precipitation			
	Cycles	HIT	LIT		Cycles	HIP	LIP
A	1970-1974	G 1997-2002	A 1970-1974	A	1970-1975	E 1990-1992	H 2005-2009
B	1975-1978	H 2003-2009	E 1988-1991	B	1976-1979	G 2000-2004	F 1993-1999
C	1979-1982	C 1979-1982	B 1975-1978	C	1980-1985	A 1970-1975	B 1976-1979
D	1983-1987	D 1983-1987	F 1992-1996	D	1986-1989	C 1980-1985	D 1986-1989
E	1988-1991	F 1992-1996	D 1983-1987	E	1990-1992	D 1986-1989	C 1980-1985
F	1992-1996	B 1975-1978	C 1979-1982	F	1993-1999	B 1976-1979	A 1970-1975
G	1997-2002	E 1988-1991	H 2003-2009	G	2000-2004	F 1993-1999	G 2000-2004
H	2003-2009	A 1970-1974	G 1997-2002	H	2005-2009	H 2005-2009	E 1990-1992

DISCUSSION OF RESULTS

Table 9 is a summary list of all climate files prepared for the study. The climate files were provided in a digital format (.hcd) that was importable into the MEPDG. A brief description of each climate file is provided below.

- MEPDG climate files are the climate files within the MEPDG software. The locations are generally associated with airports, and the number of years of data in each climate file varies. Details on these files are listed in Table 1.
- Historic climate files were prepared as part of the study. One file was created for each parish and each file contains a complete set of data from 1970 to 2010. Details on how each file was generated are described in the "Developing Historic Climate Files" section.
- Future climate files were prepared by applying projected changes in climate based on global and regional models to the 40-year historic climate data. One future climate file was created for each parish and each file contains a complete set of data from 2010 to 2050. Details on how each file was generated are described in the "Developing Future Climate Files" section.
- Random climate files were prepared by dividing the 40-year historic climate file into four- to seven-year temperature cycles and randomly re-sorting the cycles into a modified 40-year data set. This process randomly changes the chronologic sequence of extreme annual temperature periods. The modified file was adjusted by the future global and regional models to create a random future climate file. One random climate file was created for each climate zone and contains a complete set of data from 2010 to 2050. Details on how each file was generated are described in the "Developing Random Climate Files" section.

Extreme climate files were prepared in order to produce the weakest pavement conditions. Extremes were developed for high temperature and for heavy precipitation. The modified files were adjusted by the future global and regional models to create a random future climate file. One random climate file was created for each climate zone and contains a complete set of 40-year data set. A brief description for each file is given next and the details are described in the "Developing Extreme Climate Files" section.

- High Intensity Temperature (HIT) climate files were prepared by manually sorting the climate cycles developed for the random climate files into a sequence with the cycles containing the highest temperatures at the beginning of the 40-year file.
- Low Intensity Temperature (LIT) climate files were prepared by manually reversing the sort used for HIT files into a sequence with the cycles containing the lowest temperatures at the beginning of the 40-year file.
- High Intensity Precipitation (HIP) climate files were prepared by identifying precipitation cycles in the historic climate file and manually sorting the climate cycles into a sequence with the cycles containing the heaviest precipitation at the beginning of the 40-year file.
- Low Intensity Precipitation (LIP) climate files were prepared by manually reversing the sort used for HIP files into a sequence with the cycles containing the lowest precipitation at the beginning of the 40-year file.

Table 9
Climate files developed for the study

Climate File Name (1)	Description	Discussion
MEPDG	Climate files included with MEPDG software. Each file contains less than 20 years of recent climate data at locations not uniformly distributed across the state.	Business as usual. Uses narrow window of historic data for predicting future pavement performance.
Historic	Climate files containing 40 years of historic data from 1970 to 2010 for each parish.	Good climate input data for calibrating MEPDG models. Allows a match of historic climate data with pavement performance data.
Future	Climate files containing 40 years of data for nine climate zones adjusted for projected changes in climate from global and regional models.	Better climate input data for predicting future pavement performance that reflects long-term climate trends, but will still use the historic year-to-year sequence.
Random or Random Future	The 40-year historic data for nine climate zones randomly re-sorted to change the chronologic sequence of extreme annual periods, then adjusted by projected global and regional models.	Best climate input data for predicting future pavement performance. The data reflects long-term climate trends and is an unbiased series of climate cycle sequences.
Extreme includes: HIT LIT HIP LIP	The 40-year historic data for nine climate zones re-sorted to match extreme annual climate periods with the weakest pavement conditions, then adjusted by projected global and regional models.	These climate files are intended to examine predicted future pavement performance based on a worst-case climate scenario.

(1) Note: The climate files were issued to DOTD in digital format.

CONCLUSIONS

MEPDG climate files contain less than 10 years of historic climate record and must be repeated in the MEPDG analysis to extend over the predicted performance period. The MEPDG climate data is compiled from ASOS climate databases at only nine locations across the state. The ASOS data is obtained from automated weather data collection systems not supported by a rigorous, dedicated quality control program.

Climate scientists have access to numerous types of climate data that can be merged to create a high quality historic hourly climate database. This study used several climate data sources to build complete 40-year historic climate files from 1970 to 2010. Historic data files were created for each parish in the state to give the pavement designer easy access to the correct historic climate. The data used to create these historic data sets are based on higher quality data from more locations.

Climate files for predicting future pavement performance should consider the predicted changes in global climate and not simply apply the historic climate record. Each agency needs to understand the options for building future climate files and select the option that best fits the state. The options have advantages and disadvantages based on the predictive climate models and climate patterns used. For this study, the future climate files applied a 70-year global model, adjusted for regional land features, with the base climate data randomly sorted by climate cycles. Additional future climate files were built with the intent of generating extreme climate sequences for temperature and precipitation.

RECOMMENDATIONS

This study for Louisiana makes the following recommendations:

- Historic climate input files should be used for calibrating the MEPDG distress prediction models by applying the climate record that matches the time period of the pavements used for calibration.
- Random climate input files should be used in AASHTOWare Pavement ME Design for all future pavement designs.

LIST OF ABBREVIATIONS

AC	Asphalt pavement
AR	Arkansas
ASOS	Automated Surface Observation System
AWOS	Automated Weather Observation System
COOP	Cooperative Observer Program
DOTD	Department of Transportation and Development
DARWin-ME	AASHTO Guide for Design of Pavement Structures – Mechanistic Empirical
Feet	ft.
FUT	Future climate input file
HIP	High intensity precipitation climate input file
HIST	Historic climate input file
HIT	High intensity temperature climate input file
IEM	Iowa Environmental Mesonet
Inches	in.
Inter	Intermediate asphalt lift
IRI	International roughness index
JPCP	Jointed plain concrete pavement
LA	Louisiana
Lat	Latitude
LIP	Low intensity precipitation climate input file
LIT	Low intensity temperature climate input file
Long	Longitude
max	Maximum
MEPDG	Mechanistic Empirical Pavement Design Guide
MS	Mississippi
NCEI	National Centers for Environmental Information
NWS	National Weather Service
PCC	Portland cement concrete
PG	Performance graded
RAND	Random climate input file
Stab	Stabilized subgrade layer
Std dev	Standard deviation
Surf	Surface asphalt lift
TX	Texas

REFERENCES

1. Watson, D. *Nngride: An Implementation of Natural Neighbor Interpolation*. Dave Watson Publisher, Claremont, WA, 1994.
2. Segal, M., Pan, Z., Arritt, R. W., and Takle, E. S. "On the Potential Change in Wind Power over the US due to Increases of Atmospheric Greenhouse Gases." *Renewable Energy*, Vol. 24, No. 2, 2001, pp. 235-243.
3. Pan, Z., Arritt, R. W., Takle, E. S., Gutowski, W. J., Anderson, C. J., and Segal, M. "Altered Hydrologic Feedback in a Warming Climate Introduces a 'Warming Hole." *Geophysical Research Letters*, Vol. 31, No. 17, 2004.
4. Jha, M., Pan, Z., Takle, E. S., and Gu, R. "Impacts of Climate Change on Streamflow in the Upper Mississippi River Basin: A Regional Climate Model Perspective." *Journal of Geophysical Research: Atmospheres (1984–2012)*, Vol. 109, No. D9, 2004.
5. Takle, E. S., Jha, M., Lu, E., Arritt, R. W., and Gutowski, W. J. "Streamflow in the Upper Mississippi River Basin as Simulated by SWAT Driven by 20th Century Contemporary Results of Global Climate Models and NARCCAP Regional Climate Models." *Meteorologische Zeitschrift*, Vol. 19, No. 4, pp. 341-346, 2010.
6. Pan, Z., Segal, M., Arritt, R. W., and Takle, E. S. "On the Potential Change in Solar Radiation over the US Due to Increases of Atmospheric Greenhouse Gases." *Renewable Energy*, Vol. 29, No. 11, pp. 1923-1928, 2004.
7. Takle, E. S., and Pan, Z. "Climate Change and Crop Production: Challenges to Modeling Future Scenarios." In *Climate Change and Global Food Security*. Taylor & Francis Group, Boca Raton, FL, pp. 383-403, 2005.
8. Takle, E. S., Anderson, C., Jha, M., and Gassman, P. W. "Upper Mississippi River Basin Modeling System Part 4: Climate Change Impacts on Flow and Water Quality." In *Coastal Hydrology and Processes*, Singh, V. P., and Xu, Y. J. (eds.), Water Resources Publications, LLC, Highlands Ranch, CO, pp. 135-142, 2006.
9. Gutowski, Jr., W. J., Takle, E. S., Kozak, K. A., Patton, J. C., Arritt, R. W., and Christensen, J. H. "A Possible Constraint on Regional Precipitation Intensity Changes under Global Warming." *Journal of Hydrometeorology*, Vol. 8, No. 6, pp. 1382-1396, 2007.
10. Gutowski, W. J., Willis, S. S., Patton, J. C., Schwedler, B. R., Arritt, R. W., and Takle, E. S. "Changes in Extreme, Cold-Season Synoptic Precipitation Events under Global Warming." *Geophysical Research Letters*, Vol. 35, No. 20, 2008.

11. Singh, R., Helmers, M. J., Kaleita, A. L., and Takle, E. S. “Potential Impact of Climate Change on Subsurface Drainage in Iowa’s Subsurface Drained Landscapes.” *Journal of Irrigation and Drainage Engineering*. July/August, pp. 459-466, 2009.
12. Breakah, T. M., Williams, R. C., Herzmann, D. E., and Takle, E. S. “Effects of using Accurate Climatic Conditions for Mechanistic-Empirical Pavement Design.” *Journal of Transportation Engineering*, Vol. 1, No. 1, pp. 84-90, 2

This public document is published at a total cost of $250
42 copies of this public document were published in this first printing at a cost of $250. The total cost of all printings of this document including reprints is $250. This document was published by Louisiana Transportation Research Center to report and publish research findings as required in R.S. 48:105. This material was duplicated in accordance with standards for printing by state agencies established pursuant to R.S. 43:31. Printing of this material was purchased in accordance with the provisions of Title 43 of the Louisiana Revised Statutes.