Pavement Temperature Profile Prediction

Temperature Estimate Model for Pavement Structures (TEMPS)

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Pavement Temperature Profile Prediction

Improvement of the *Heat Transfer* model [Han et al., 2011 (TAMU)]
- Enhanced boundary conditions.
- Variable pavement surface radiation properties.

Application of Finite Control Volume method (FCV) with Implicit Scheme [Zia et al., 2014 (UNR)]
- Considering discontinuity in pavement layers’ material.
- Improving the time efficiency of calculation.
Pavement Temperature Profile Prediction

Heat Transfer Model Concept

Heat Transfer Balance Between Pavement Structure & Surrounding Environment

\[
\frac{\partial T}{\partial t} = \frac{\partial}{\partial z} \left( \alpha \times \frac{\partial T}{\partial z} \right), \quad \alpha = \frac{k}{\rho \cdot c}
\]
Pavement Temperature Profile Prediction
Numerical Computation: Finite Control Volume Method (FCVM)

Energy Balance in Each of Control Elements
Pavement Temperature Profile Prediction

Standalone Software: TEMPS (Alpha Version)

Temperature Estimate Model for Pavement Structures (TEMPS)
Pavement Temperature Profile Prediction

TEMPS – Input

- **Materials**
- **Climatic Data**
- **Surface Characteristics**
- **Pavement Structure**
- **Mesh Generator**
Pavement Temperature Profile Prediction

TEMPS – Materials

Example-Montana - TEMPS

Material

- Material Type: Material1
- Identifier Color: Brown
- Specific Heat Capacity (J/kg*K): 1900
- Conductivity (W/m*K): 1.00
- Density (kg/m^3): 1500
- Description:

Table:

<table>
<thead>
<tr>
<th>Material Type</th>
<th>Identifier Color</th>
<th>Specific Heat Capacity (J/kg*K)</th>
<th>Conductivity (W/m*K)</th>
<th>Density (kg/m^3)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Asphalt Mixture</td>
<td>Black</td>
<td>921</td>
<td>1.21</td>
<td>2250</td>
</tr>
<tr>
<td>Coarse Agg.</td>
<td>Silver</td>
<td>1900</td>
<td>1.00</td>
<td>1800</td>
</tr>
<tr>
<td>Fine Agg.</td>
<td>Brown</td>
<td>1900</td>
<td>1.00</td>
<td>1500</td>
</tr>
</tbody>
</table>
Pavement Temperature Profile Prediction

TEMPS – Climatic Data

Climatic Data Sources
1. National Climate Data Center (NCDC)
   The following website provides free hourly temperature data:
   http://gis.ncdc.noaa.gov/

2. National Solar Radiation Data Base (NSRDB)
   The following website provides you with a good source for hourly air temperature, hourly solar radiation and hourly wind speed data which are available mostly for airports:
   http://nedc.nrel.gov/solar/old_data/nsrdb/

3. Long Term Pavement Performance (LTPP)
   The following website provides LTPP data, which are monitored on pavement sections in the United States over years:
   http://www.infospave.com/
Pavement Temperature Profile Prediction

TEMPS – Surface Characteristics
Pavement Temperature Profile Prediction

TEMPS – Pavement Structure
Pavement Temperature Profile Prediction

TEMPS – Mesh Generator
Pavement Temperature Profile Prediction

TEMPS – Run Analysis

Time Efficiency of Computation: Implicit Scheme

Run time for 1 years analysis period
(3.10 GHz proc. and 4.00 GB RAM)

< 10 seconds using 1 hour time step*

* Note: 1 hour time step was chosen without jeopardizing the model accuracy for prediction.
Pavement Temperature Profile Prediction
TEMPS – Output Results
Pavement Temperature Profile Prediction

TEMPS – Output Results
Pavement Temperature Profile Prediction

TEMPS – Output Summary

Example-Montana - TEMPS

Pavement Temperature Profile Summary

<table>
<thead>
<tr>
<th>Date-Time</th>
<th>Depth</th>
<th>z = 0.01 m</th>
<th>z = 0.02 m</th>
<th>z = 0.03 m</th>
<th>z = 0.04 m</th>
<th>z = 0.05 m</th>
<th>z = 0.06 m</th>
<th>z = 0.07 m</th>
<th>z = 0.08 m</th>
<th>z = 0.09 m</th>
<th>z = 0.1 m</th>
</tr>
</thead>
<tbody>
<tr>
<td>12/1/2001</td>
<td>0:00</td>
<td>-1.14°C</td>
<td>-1.17°C</td>
<td>-1.2°C</td>
<td>-1.23°C</td>
<td>-1.26°C</td>
<td>-1.29°C</td>
<td>-1.32°C</td>
<td>-1.35°C</td>
<td>-1.38°C</td>
<td>-1.41°C</td>
</tr>
<tr>
<td>12/1/2001</td>
<td>1:00</td>
<td>-1.39°C</td>
<td>-1.37°C</td>
<td>-1.36°C</td>
<td>-1.38°C</td>
<td>-1.40°C</td>
<td>-1.42°C</td>
<td>-1.45°C</td>
<td>-1.47°C</td>
<td>-1.49°C</td>
<td>-1.51°C</td>
</tr>
<tr>
<td>12/1/2001</td>
<td>2:00</td>
<td>-1.47°C</td>
<td>-1.46°C</td>
<td>-1.45°C</td>
<td>-1.44°C</td>
<td>-1.43°C</td>
<td>-1.42°C</td>
<td>-1.40°C</td>
<td>-1.38°C</td>
<td>-1.35°C</td>
<td>-1.32°C</td>
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<tr>
<td>12/1/2001</td>
<td>3:00</td>
<td>-1.29°C</td>
<td>-1.33°C</td>
<td>-1.36°C</td>
<td>-1.38°C</td>
<td>-1.40°C</td>
<td>-1.42°C</td>
<td>-1.45°C</td>
<td>-1.48°C</td>
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<td>-1.55°C</td>
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<tr>
<td>12/1/2001</td>
<td>4:00</td>
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<td>-1.06°C</td>
<td>-1.13°C</td>
<td>-1.2°C</td>
<td>-1.25°C</td>
<td>-1.30°C</td>
<td>-1.33°C</td>
<td>-1.36°C</td>
<td>-1.38°C</td>
<td>-1.41°C</td>
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<tr>
<td>12/1/2001</td>
<td>5:00</td>
<td>-1.14°C</td>
<td>-1.16°C</td>
<td>-1.19°C</td>
<td>-1.23°C</td>
<td>-1.26°C</td>
<td>-1.30°C</td>
<td>-1.33°C</td>
<td>-1.36°C</td>
<td>-1.38°C</td>
<td>-1.41°C</td>
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<tr>
<td>12/1/2001</td>
<td>6:00</td>
<td>-1.16°C</td>
<td>-1.19°C</td>
<td>-1.22°C</td>
<td>-1.24°C</td>
<td>-1.26°C</td>
<td>-1.30°C</td>
<td>-1.33°C</td>
<td>-1.36°C</td>
<td>-1.38°C</td>
<td>-1.41°C</td>
</tr>
<tr>
<td>12/1/2001</td>
<td>7:00</td>
<td>-0.91°C</td>
<td>-0.99°C</td>
<td>-1.06°C</td>
<td>-1.12°C</td>
<td>-1.17°C</td>
<td>-1.22°C</td>
<td>-1.27°C</td>
<td>-1.31°C</td>
<td>-1.35°C</td>
<td>-1.38°C</td>
</tr>
<tr>
<td>12/1/2001</td>
<td>8:00</td>
<td>-0.86°C</td>
<td>-0.93°C</td>
<td>-0.99°C</td>
<td>-1.05°C</td>
<td>-1.11°C</td>
<td>-1.16°C</td>
<td>-1.21°C</td>
<td>-1.25°C</td>
<td>-1.30°C</td>
<td>-1.34°C</td>
</tr>
<tr>
<td>12/1/2001</td>
<td>9:00</td>
<td>-0.57°C</td>
<td>-0.68°C</td>
<td>-0.78°C</td>
<td>-0.87°C</td>
<td>-0.95°C</td>
<td>-1.03°C</td>
<td>-1.09°C</td>
<td>-1.16°C</td>
<td>-1.21°C</td>
<td>-1.27°C</td>
</tr>
<tr>
<td>12/1/2001</td>
<td>10:00</td>
<td>0.53°C</td>
<td>0.23°C</td>
<td>-0.02°C</td>
<td>-0.24°C</td>
<td>-0.42°C</td>
<td>-0.58°C</td>
<td>-0.72°C</td>
<td>-0.84°C</td>
<td>-0.95°C</td>
<td>-1.05°C</td>
</tr>
</tbody>
</table>

General Summary

- Overall Minimum Pavement Temperature: -21.12°C Occurred On: 3/8/2002 - 8:00, At the Depth of: 0.01 m
- Overall Maximum Pavement Temperature: 51.04°C Occurred On: 7/12/2002 - 16:00, At the Depth of: 0.01 m

Export General Summary
Pavement Temperature Profile Prediction

TEMPS – Output Summary

Example-Montana - TEMPS

Pavement Temperature Profile Summary

Date-Time | Depth | z = 0.01 m | z = 0.02 m | z = 0.03 m | z = 0.04 m | z = 0.05 m | z = 0.06 m | z = 0.07 m | z = 0.08 m | z = 0.09 m | z = 0.1 m
----------|-------|------------|------------|------------|------------|------------|------------|------------|------------|------------|------------|
12/1/2001 - 0:00 | -1.14°C | -1.17°C | -1.2°C | -1.23°C | -1.26°C | -1.29°C | -1.32°C | -1.35°C | -1.38°C | -1.41°C | -1.41°C |
12/1/2001 - 1:00 | -1.39°C | -1.37°C | -1.36°C | -1.39°C | -1.42°C | -1.44°C | -1.47°C | -1.49°C | -1.5°C | -1.5°C | -1.5°C |
12/1/2001 - 2:00 | -1.47°C | -1.46°C | -1.45°C | -1.44°C | -1.45°C | -1.46°C | -1.47°C | -1.49°C | -1.5°C | -1.5°C | -1.5°C |
12/1/2001 - 3:00 | -1.29°C | -1.33°C | -1.36°C | -1.42°C | -1.44°C | -1.46°C | -1.48°C | -1.5°C | -1.5°C | -1.5°C | -1.5°C |
12/1/2001 - 4:00 | -0.97°C | -1.06°C | -1.13°C | -1.25°C | -1.34°C | -1.42°C | -1.45°C | -1.49°C | -1.5°C | -1.5°C | -1.5°C |
12/1/2001 - 5:00 | -1.14°C | -1.18°C | -1.19°C | -1.23°C | -1.26°C | -1.33°C | -1.38°C | -1.43°C | -1.43°C | -1.38°C | -1.43°C |
12/1/2001 - 6:00 | -1.16°C | -1.22°C | -1.27°C | -1.28°C | -1.33°C | -1.39°C | -1.42°C | -1.38°C | -1.38°C | -1.38°C | -1.38°C |
12/1/2001 - 7:00 | -0.91°C | -1.06°C | -1.17°C | -1.12°C | -1.17°C | -1.21°C | -1.25°C | -1.31°C | -1.31°C | -1.31°C | -1.31°C |
12/1/2001 - 8:00 | -0.86°C | -0.93°C | -0.99°C | -0.99°C | -0.95°C | -0.95°C | -0.95°C | -0.95°C | -0.95°C | -0.95°C | -0.95°C |
12/1/2001 - 9:00 | -0.57°C | -0.68°C | -0.78°C | -0.87°C | -0.95°C | -1.03°C | -1.09°C | -1.16°C | -1.21°C | -1.27°C | -1.27°C |
12/1/2001 - 10:00 | 0.53°C | 0.23°C | -0.02°C | -0.24°C | -0.42°C | -0.58°C | -0.72°C | -0.95°C | -1.05°C | -1.16°C | -1.16°C |

General Summary

Start Date: Saturday, December 1, 2001
End Date: Saturday, November 30, 2002

Detailed Summary

Date | Average Pavement Temperature (°C) | Minimum Pavement Temperature (°C) | Maximum Pavement Temperature (°C) | Pavement Temperature Standard Deviation (°C)
-----|----------------------------------|----------------------------------|----------------------------------|----------------------------------|
12/1/2001 | 1.64 | -1.47 | 6.74 | 2.81
12/2/2001 | 3.77 | 1.23 | 8.16 | 2.39
12/3/2001 | 3.16 | 0.31 | 8.58 | 2.64
12/4/2001 | 0.25 | -2.33 | 4.51 | 2.25
12/5/2001 | -1.84 | -3.79 | 2.79 | 1.93
12/6/2001 | 0.13 | -3.01 | 5.49 | 2.75
12/7/2001 | 1.21 | -2.21 | 6.39 | 2.75
12/8/2001 | 5.52 | 1.52 | 11.81 | 3.41
12/9/2001 | 4.1 | -2.33 | 8.69 | 2.97
Pavement Temperature Profile Prediction

TEMPS – Predicted versus Measured

Great Falls, MT at depth of 0.09 m (3.5 inch)

Particle Swarm Optimization (PSO) Algorithm:
Single yearly surface characteristics
Pavement Temperature Profile Prediction
TEMPS – Predicted versus Measured

Great Falls, MT at depth of 0.09 m (3.5 inch)

Particle Swarm Optimization (PSO) Algorithm:
Single yearly surface characteristics

Optimization need to be refined to include monthly surface characteristics
Pavement Temperature Profile Prediction

TEMPS – Additional Improvements

• Optimize the surface characteristics for the US (Albedo, Emissivity, Absorption) using Particle Swarm Optimization (PSO) Algorithm
  – Monthly or seasonal values.

• Create/Include input files for LTPP SMP sections.

• Provide a summary of the average 7-day pavement temperature at various depths.

• Provide a summary of pavement cooling/warming rates.
Thank You!