The Impact of Cloud Type on Surface Radiation and Road Pavement Temperature

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Computing Mentor: Amanda Anderson
Writing Mentor: Jeff Custer
Impacts of Adverse Weather on Roads

- **Safety** – 24% of U.S. Highway crashes are weather-related; ~673,000 injuries
- **Economic** – Avg. cost per crash is $14,100; congestion costs ~$9.5 billion
- **Environmental** – Air quality and local watershed pollution
- **Social** – Inconvenience of traffic delays

*Fig 1. National Weather Service tracked average annual fatalities (1995 – 2008) due to weather hazards (USDOT, 2010).*
Tire Friction & Temperature

- Khasawneh and Liang (2012)
- As temperature increases, tire friction (grip) decreases
- Tire expands vertically, less surface area in contact with ground

*BPN – British Pendulum Number, surface friction measurement*
Motivation

- Forecast systems are impacted by inaccurate radiation forecasts
- Cloud amount and type influences radiation forecasts
- Inclusion of cloud type may improve forecasts for a variety of end-users
Pavement Temperature Energy Balance Models

Road Weather Information System stations

Numerical Weather Prediction Model

Pavement Temperature Energy Balance Model

Pavement Temperature Forecast

Weather Decision Support for:
- Snow removal/deicing
- Road maintenance
- Driver awareness

Walker et al. 2011
Pavement Temperature Modeling Improvements

Better Cloud Type and Radiation Data

Improved Weather Decision Support & Increased Safety

More Accurate Pavement Temperature Forecast

Road Weather Information System stations

Numerical Weather Prediction Model

Pavement Temperature Energy Balance Model

Walker et al. 2011
Naval Research Laboratory Cloud Classifier

- Utilizes combination of visible and infrared satellite channels to produce cloud type
- Pixel-by-pixel brightness thresholds
- Day and night operation

1915 UTC 20 June 2012 NRL
Case Study Analysis

- 9 cases from Salisbury, NC, May-June 2012
- Radiation – Cloud Type Distribution Analyses
- Theoretical Max Radiation and Water Vapor Assessments
Bulk Statistical Assessment

- June 2012 OK-MESONET
- Radiation – Cloud Type Distribution Analyses

Adapted from Clarus Archive data
Case Studies Vs. OK-Mesonet

OK-Mesonet distributions similar to case studies
Summary of All 9 Cases

Overall Cases Percent Max Radiation - Cloud Type Distribution

Percent of Max Radiation

- Low clouds
  ~20%
- Mid-level clouds*
  ~34%
- High clouds
  ~40%
- Cumuliform clouds
  ~30%
- Clear
  ~60%
Tactical Forecasting

29 May 2012 Mean Radiation Time Series

<table>
<thead>
<tr>
<th>Time (UTC)</th>
<th>Mean Radiation (Wm⁻²)</th>
<th>Cloud Type</th>
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<tbody>
<tr>
<td>1615</td>
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<tr>
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</tr>
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- 45 min radiation reduction
- 25 min radiation recovery
Tactical Forecasting

29 May 2012 Mean Radiation Time Series

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Challenges: Clear Day?

- Noisy radiation observations on this “clear” day
- Liquid water on the radiometer shows notable signal
Challenges: Clear Day?

- Noisy radiation observations on this “clear” day
- Liquid water on the radiometer shows notable signal
Conclusions

• It is plausible to remotely sense clouds and quantify their impact on radiation

• Tactical forecasting is also possible

• Clouds and other atmospheric effects impede 60-80% of total possible radiation

• Still uncertainty with other influences on radiation
  ➢ Water vapor?
  ➢ Aerosols?
Future Work

• Compute regression analysis for OK-Mesonet
• Similar assessment for other regions / seasons
• Test other important cloud properties
• Road pavement temperature + radiation analyses
Acknowledgments

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- Science Mentor: Michael Chapman
- Computer Mentor: Amanda Anderson
- Writing Mentor: Jeff Custer
- Sheldon Drobot
- David Currier
- Paul Kucera
- Rebecca Batchelor
- Research Applications Laboratory (RAL)
- UCAR Community
Summary

- Pavement temperature is crucial to vehicle response to weather conditions
- Clouds are the primary source of forecast error due to influence on surface radiation
- Better inclusion of clouds in forecast systems will improve pavement temperature modeling

Thank You, Questions?
## Cloud Type Groups

### Height Cloud Type Groups

<table>
<thead>
<tr>
<th>Low</th>
<th>Mid</th>
<th>High</th>
<th>Cumuliform</th>
</tr>
</thead>
</table>
| Stratus  
Stratocumulus | Altocumulus  
Altostratus | Cirrus  
Cirrostratus  
Cirrocumulus | Cumulus  
Cumulus Congestus  
Cumulonimbus  
Cirrostratus Anvil |

### Thickness / Coverage Cloud Type Groups

<table>
<thead>
<tr>
<th>Thick</th>
<th>Thin</th>
<th>Scattered</th>
</tr>
</thead>
</table>
| Stratus  
Stratocumulus  
Cirrostratus Anvil  
Cumulonimbus | Altostratus  
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Cirrostratus | Cumulus  
Altocumulus  
Cirrocumulus  
Cumulus Congestus |
Cloud Type – Location Pixel Matching

- 9 pixel box, 8x8 km
- Most frequent cloud type selected – grouped by height
Theoretical Solar Max Calculations

\[ F = S_0 \, (\sin \theta) \]

- \( F \): top of atmosphere solar flux (Wm\(^{-2}\))
- \( S_0 \): the solar constant: 1370 Wm\(^{-2}\)
- \( \theta \): local solar zenith angle
Another Clear Day? – Water Vapor

Clear day comes nowhere near maximum radiation

Mean Radiation Vs. Mean Water Vapor for all 9 cases
Correlation = -0.902
OK-Mesonet ALT Cloud Groups

OK-Mesonet Cloud Type Grouped By Thickness / Coverage

Surface Solar Radiation (W m⁻²)

Cloud Type

- Thick
- Thin
- Scattered
- Clear

Sample sizes:
- Thick: n=35882
- Thin: n=6999
- Scattered: n=8075
- Clear: n=205931
Another Tactical Forecasting Case

### 3 June 2012 Mean Radiation Time Series

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<tr>
<td>1731</td>
<td>821.6667</td>
<td>Clear</td>
</tr>
<tr>
<td>1745</td>
<td>933.4</td>
<td>Cumuliform</td>
</tr>
<tr>
<td>1815</td>
<td>764.8</td>
<td>Clear</td>
</tr>
<tr>
<td>1831</td>
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</tr>
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<td>318</td>
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<td>1915</td>
<td>902.4</td>
<td>Clear</td>
</tr>
<tr>
<td>Case Date (2012)</td>
<td>Cloud / Weather Conditions</td>
<td>Synoptic Comments</td>
</tr>
<tr>
<td>-----------------</td>
<td>------------------------------------------------</td>
<td>--------------------------------------------------------</td>
</tr>
<tr>
<td>19 May</td>
<td>Variable, mostly high clouds</td>
<td>Tropical system offshore (Beryl)</td>
</tr>
<tr>
<td>23 May</td>
<td>Overcast with AM rain, late clearing</td>
<td>Stationary front, severe weather to the east</td>
</tr>
<tr>
<td>24 May</td>
<td>Variable with AM mist/fog, late clearing</td>
<td>Summer southeast moisture flow</td>
</tr>
<tr>
<td>29 May</td>
<td>Mostly cloudy, PM thunderstorms</td>
<td>Tropical depression (Beryl) combined with cold front</td>
</tr>
<tr>
<td>30 May</td>
<td>Overcast with AM rain/mist, PM partly cloudy</td>
<td>Tropical depression (Beryl) combined with cold front</td>
</tr>
<tr>
<td>2 June</td>
<td>Partly to mostly cloudy all day</td>
<td>AM cold front</td>
</tr>
<tr>
<td>3 June</td>
<td>Mostly clear with few/scattered high clouds</td>
<td>Clear, warm front ahead of next system</td>
</tr>
<tr>
<td>8 June</td>
<td>Data Not Available</td>
<td>Clear, systems north and south</td>
</tr>
<tr>
<td>9 June</td>
<td>Data Not Available</td>
<td>Gulf Coast storm approaching from southwest</td>
</tr>
</tbody>
</table>
British Pendulum Number

• British Pendulum Test
• Pendulum swings with a rubber sensor at the bottom
• Rubber sensor grazes the surface in question
• BPN = 100 x coefficient of friction ($\mu$)

Khasawneh and Liang (2012)