Time series analysis of soil freeze-thaw processes in Indiana

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Outline

• Why is soil frost important?
• Objectives
• Study area
• Methodology
  ▪ Data quality control
  ▪ Data processing
  ▪ Auto-correlation and trend analysis
• Results
• Conclusions
Why is soil frost important?

- Soil ice reduces infiltration, cohesion and soil strength

![Diagram showing soil structure and ice formation](image)

- Increases soil erosion potential during thawing
Why is soil frost important?

- Increases rapid runoff response during snowmelt

- Effects land surface energy balance fluxes
Objectives

• To identify variability in meteorological and soil frost variables at different sites

• To study how annual meteorological variables effect soil freeze-thaw processes

• To identify trends in soil frost variables and to compare them with existing trends in other climatic variables
Study Area

Pinney-Purdue Agricultural Center (PPAC) near Wanatah
Soil – Tracy sandy loam

Agronomy Center for Research and Education (ACRE) near West Lafayette
Soil – Russell silt loam

Southern Indiana Purdue Agricultural Center (SIPAC) near Dubois
Soil – Zanesville silt loam

Soil temperature data collecting station (since 1966)
**Methodology**

- **Missing Dates and Data Identification**
- **Cumulative Deviation Test**
- **Data Quality Control**
- **Extreme temperature**
- **Consecutive values**
- **Days min $T_{soil} \leq 0 \, ^{o}C$**
- **Mean winter soil and air temperatures**
- **NCDC Meteorological Data**
- **Auto-Correlation check**
- **Data Processing based on Water Year**
- **Linear Regression Test**
- **Cumulative Deviation Test**
- **Trend Analysis**
- **Mann Kendall’s Test**
- **Freeze-Thaw Cycles**
- **Annual Snow Depth and Snowfall**
- **Snowfall**
- **Air Temperature ($T_{air}$)**
- **Soil Temperature ($T_{soil}$)**
- **Snow Depth**
- **Precipitation**
## Results

### Annual average statistics

<table>
<thead>
<tr>
<th>Meteorological Variables</th>
<th>PPAC</th>
<th>ACRE</th>
<th>SIPAC</th>
</tr>
</thead>
<tbody>
<tr>
<td>Snow (cm)*</td>
<td>107.8</td>
<td>53.9</td>
<td>23.2</td>
</tr>
<tr>
<td>SCI (cm-day)*</td>
<td>710.5</td>
<td>331.5</td>
<td>80.8</td>
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<tr>
<td>Days minimum $T_{\text{air}} \leq 0^\circ C$</td>
<td>137.4</td>
<td>131.3</td>
<td>108.0</td>
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<tr>
<td>Precipitation (cm)</td>
<td>94.9</td>
<td>95.1</td>
<td>119.3</td>
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</tbody>
</table>

*SIPAC average statistics estimated from 1985 - 2004*
Average statistics for selected soil frost variables.

<table>
<thead>
<tr>
<th></th>
<th>Bare soil</th>
<th>PPAC</th>
<th>ACRE</th>
<th>SIPAC</th>
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</thead>
<tbody>
<tr>
<td><strong>Soil freeze-thaw cycles</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5 cm</td>
<td>29.3</td>
<td>19.5</td>
<td>9.1</td>
<td></td>
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<tr>
<td>10 cm</td>
<td>4.9</td>
<td>9.3</td>
<td>9.5</td>
<td></td>
</tr>
<tr>
<td>20 cm</td>
<td>-</td>
<td>5.3</td>
<td>0.7</td>
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<tr>
<td><strong>Soil frost days</strong></td>
<td></td>
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</tr>
<tr>
<td>5 cm</td>
<td>79.3</td>
<td>61.1</td>
<td>22.8</td>
<td></td>
</tr>
<tr>
<td>10 cm</td>
<td>24.5</td>
<td>48.8</td>
<td>22.4</td>
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</tr>
<tr>
<td>20 cm</td>
<td>-</td>
<td>33.2</td>
<td>3.1</td>
<td></td>
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<tr>
<td><strong>Freeze-thaw cycles per soil frost days</strong></td>
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<tr>
<td>5 cm</td>
<td>0.37</td>
<td>0.32</td>
<td>0.40</td>
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<tr>
<td>10 cm</td>
<td>0.20</td>
<td>0.19</td>
<td>0.42</td>
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<tr>
<td>20 cm</td>
<td>-</td>
<td>0.16</td>
<td>0.23</td>
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</tbody>
</table>

PPAC – Annual snowfall (107.8 cm), Soil – Tracy sandy loam  
ACRE – Annual snowfall (53.9 cm), Soil - Russell silt loam  
SIPAC – Annual snowfall (23.2 cm), Soil – Zanesville silt loam
Selected meteorological variables

1. **PPAC**
   - Annual snow (cm)

2. **ACRE**
   - SCI (cm-days)

3. **SIPAC**
   - Mean Max T_air (°C)

Water Year
Bare soil at 5 cm soil depth

PPAC

ACRE

SIPAC

Soil frost days

Mean Min $T_{soil}$ (°C)

Freeze-thaw cycles

Water Year
Bare soil at 10 cm soil depth

**PPAC**

1a

Soil frost days

2a

Mean Min \(T_{soil} \) (°C)

3a

Water Year


4a

**ACRE**

1b

Freeze-thaw cycles

2b

Mean Max \(T_{soil} \) (°C)

3b

Water Year


4b

**SIPAC**

1c

2c

3c

4c
ACRE: 10 cm bare soil

Earlier Snowfall

Earlier Soil frost
Conclusions

Observational records from 1966 till 2004 indicate:

• Soil frost dynamics are similar between northern and central sites.

• Number of freeze-thaw cycles and soil frost days are increasing in northern and southern sites while decreasing at central site.

• Snow cover on ground surface reduces soil freeze-thaw cycles.

• Inverse relationship between mean seasonal minimum soil temperature and soil frost is observed.
Questions!