Temporal Comparison of Atmospheric Stability Classification Methods

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Acknowledgement of Data
- Calvert Cliffs
  - Richard Conatser
- Nine Mile Point
  - Tom Galletta

Basis of Problem
- Pilgrim Station was experiencing some problems with the upper-level temperature indication used to derive delta-T on its primary tower
- **Question**: Can Pilgrim substitute data from its backup tower, or another estimate of stability class, to meet data recovery goals?
- **Proposed Solution**: Compare various estimates of stability class to determine suitability for substitution

Stability Class Determination
- Safety Guide 23 recognizes two methods for determining stability class
  - Delta-temperature between two levels of a tower reflects potential for *vertical* mixing based on adiabatic lapse rate
  - Sigma theta, or variability of wind direction fluctuations, reflects potential for *horizontal* mixing
  - Which is better? Should they compare?

Delta-T Method
- Employed by most plants as their primary method for determining stability class
- Most plants measure temperature differential between sensors at the top of the tower, and at the standard height of 10 meters ("bottom" of tower)
- Some plants have temperature sensor at midpoint, and can derive multiple delta-T values (Top-Bottom, Middle-Bottom)

Sigma Theta Method
- Based on the standard deviation of the wind direction obtained over the same period of time used to determine average wind direction, usually 15 minutes (NUREG-0654)
- Useful for determining stability class for "short" towers, where conditions are measured at a single level (10 meters)
- Many plant use a 10-meter tower with single-level instruments as their backup tower
### Pasquill Gifford Stability Class

<table>
<thead>
<tr>
<th>Stability Classification</th>
<th>Pasquill Category</th>
<th>Delta-T degrees C/100m</th>
<th>Sigma-theta degrees</th>
</tr>
</thead>
<tbody>
<tr>
<td>Extremely unstable</td>
<td>A</td>
<td>&lt;-1.9</td>
<td>&gt;22.5</td>
</tr>
<tr>
<td>Moderately unstable</td>
<td>B</td>
<td>-1.9 to -1.7</td>
<td>17.5 to 22.5</td>
</tr>
<tr>
<td>Slightly unstable</td>
<td>C</td>
<td>-1.7 to -1.5</td>
<td>12.5 to 17.5</td>
</tr>
<tr>
<td>Neutral</td>
<td>D</td>
<td>-1.5 to -0.5</td>
<td>7.5 to 12.5</td>
</tr>
<tr>
<td>Slightly stable</td>
<td>E</td>
<td>-0.5 to 1.5</td>
<td>3.8 to 7.5</td>
</tr>
<tr>
<td>Moderately stable</td>
<td>F</td>
<td>1.5 to 4.0</td>
<td>2.1 to 3.8</td>
</tr>
<tr>
<td>Extremely stable</td>
<td>G</td>
<td>&gt;4.0</td>
<td>&lt;2.1</td>
</tr>
</tbody>
</table>

### Dispersion X/Q Equation

\[ \frac{X}{Q} = \frac{1}{2\sigma_x,\sigma_z,\mu} \cdot \exp \left( -\frac{y^2}{2\sigma_y^2} \right) \cdot \exp \left[ -\frac{(z-h)^2}{2\sigma_z^2} \right] \cdot \exp \left[ -\frac{(z+h)^2}{2\sigma_z^2} \right] \]

- \( \sigma_x \) = Horizontal Dispersion Component
- \( \sigma_z \) = Vertical Dispersion Component, Including Reflection
- \( y \) = distance from release point
- \( z \) = terrain height above ground at distance 'y'
- \( h \) = elevation of release point above ground

### Horizontal Dispersion Coefficient

<table>
<thead>
<tr>
<th>Distance (km)</th>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
<th>E</th>
<th>F</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.5</td>
<td>5.0E-06</td>
<td>1.4E-05</td>
<td>3.6E-05</td>
<td>9.8E-05</td>
<td>1.8E-04</td>
<td>4.1E-04</td>
</tr>
<tr>
<td>1</td>
<td>7.2E-07</td>
<td>3.7E-06</td>
<td>1.0E-05</td>
<td>3.0E-05</td>
<td>5.9E-05</td>
<td>1.4E-04</td>
</tr>
<tr>
<td>3</td>
<td>1.9E-08</td>
<td>4.2E-07</td>
<td>1.3E-06</td>
<td>5.2E-06</td>
<td>1.1E-05</td>
<td>2.6E-05</td>
</tr>
<tr>
<td>10</td>
<td>1.8E-10</td>
<td>3.9E-08</td>
<td>1.5E-07</td>
<td>8.3E-07</td>
<td>1.9E-06</td>
<td>5.0E-06</td>
</tr>
</tbody>
</table>

### Vertical Dispersion Coefficient

<table>
<thead>
<tr>
<th>Distance (km)</th>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
<th>E</th>
<th>F</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.5</td>
<td>4.3E-06</td>
<td>7.5E-06</td>
<td>6.3E-06</td>
<td>3.6E-07</td>
<td>4.2E-09</td>
<td>6.0E-15</td>
</tr>
<tr>
<td>1</td>
<td>7.1E-07</td>
<td>3.2E-06</td>
<td>6.1E-06</td>
<td>4.3E-06</td>
<td>1.1E-06</td>
<td>9.7E-09</td>
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<td>2.0E-06</td>
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<tr>
<td>10</td>
<td>1.8E-10</td>
<td>3.9E-08</td>
<td>1.5E-07</td>
<td>7.5E-07</td>
<td>1.5E-06</td>
<td>2.2E-06</td>
</tr>
</tbody>
</table>

### Ground-Level Release X/Q

**Wind Speed = 5 m/s (~11 mph)**

<table>
<thead>
<tr>
<th>Distance (km)</th>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
<th>E</th>
<th>F</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.5</td>
<td>5.0E-06</td>
<td>1.4E-05</td>
<td>3.6E-05</td>
<td>9.8E-05</td>
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<td>2.6E-05</td>
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<tr>
<td>10</td>
<td>1.8E-10</td>
<td>3.9E-08</td>
<td>1.5E-07</td>
<td>8.3E-07</td>
<td>1.9E-06</td>
<td>5.0E-06</td>
</tr>
</tbody>
</table>

### Elevated Release X/Q

**Stack Height = 60 m, Wind Speed = 5 m/s**

<table>
<thead>
<tr>
<th>Distance (km)</th>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
<th>E</th>
<th>F</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.5</td>
<td>4.3E-06</td>
<td>7.5E-06</td>
<td>6.3E-06</td>
<td>3.6E-07</td>
<td>4.2E-09</td>
<td>6.0E-15</td>
</tr>
<tr>
<td>1</td>
<td>7.1E-07</td>
<td>3.2E-06</td>
<td>6.1E-06</td>
<td>4.3E-06</td>
<td>1.1E-06</td>
<td>9.7E-09</td>
</tr>
<tr>
<td>3</td>
<td>1.9E-08</td>
<td>4.2E-07</td>
<td>1.3E-06</td>
<td>3.4E-06</td>
<td>4.0E-06</td>
<td>2.0E-06</td>
</tr>
<tr>
<td>10</td>
<td>1.8E-10</td>
<td>3.9E-08</td>
<td>1.5E-07</td>
<td>7.5E-07</td>
<td>1.5E-06</td>
<td>2.2E-06</td>
</tr>
</tbody>
</table>
Pilgrim Meteorological Towers

- **Primary Tower**
  - 220-ft tall, based at ~80 ft above sea level on vegetated area
  - 270m from ocean
  - Effective height = 300 ft
  - Wind and temperature at top and 10m
- **Secondary (Backup) Tower**
  - 160-ft tall, based at ~20 ft above sea level in parking lot 100m from ocean
  - Effective height = 180 ft
  - Wind and temperature at top and 10m
- Hourly averages for 3-year period, yielded ~25,000 observations

### Stability Class Frequencies

#### Pilgrim Station

<table>
<thead>
<tr>
<th>Stability Class</th>
<th>Frequency</th>
<th>P</th>
<th>S</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>2838</td>
<td>1751</td>
<td>821</td>
</tr>
<tr>
<td>B</td>
<td>1968</td>
<td>240</td>
<td>279</td>
</tr>
<tr>
<td>C</td>
<td>1528</td>
<td>173</td>
<td>261</td>
</tr>
<tr>
<td>D</td>
<td>1328</td>
<td>384</td>
<td>481</td>
</tr>
<tr>
<td>E</td>
<td>9236</td>
<td>70</td>
<td>66</td>
</tr>
<tr>
<td>F</td>
<td>5734</td>
<td>138</td>
<td>35</td>
</tr>
<tr>
<td>G</td>
<td>23645</td>
<td>82</td>
<td>25</td>
</tr>
</tbody>
</table>

### Agreement Matrix

#### Agreement Matrix Summary: Summation of Diagonals

<table>
<thead>
<tr>
<th>Stability Class Difference</th>
<th>Primary Tower Conservative</th>
<th>Secondary Tower Conservative</th>
</tr>
</thead>
<tbody>
<tr>
<td>Match</td>
<td>12052</td>
<td>51.0%</td>
</tr>
<tr>
<td>1</td>
<td>4273</td>
<td>18.1%</td>
</tr>
<tr>
<td>2</td>
<td>962</td>
<td>4.2%</td>
</tr>
<tr>
<td>3</td>
<td>570</td>
<td>2.4%</td>
</tr>
<tr>
<td>4</td>
<td>118</td>
<td>0.5%</td>
</tr>
<tr>
<td>5</td>
<td>163</td>
<td>0.7%</td>
</tr>
<tr>
<td>6</td>
<td>62</td>
<td>0.3%</td>
</tr>
<tr>
<td>Total</td>
<td>6188</td>
<td>26.2%</td>
</tr>
</tbody>
</table>

### Agreement Graph

#### Pilgrim Delta-T Primary:Secondary

- **Primary Delta-T vs. Secondary Delta-T**

### Class A Hour Distribution

#### Pilgrim Delta-T Primary:Secondary

- **Class A Stability vs. Time of Day**

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Sejkora: Temporal Comparison of Atmospheric Stability Classification Methods
Is Pilgrim Unique?

- Need to obtain sigma theta information, which isn’t available at Pilgrim
- Obtain data from other ‘coastal’ sites
  - Calvert Cliffs
  - Nine Mile Point
- Perform similar types of evaluations
  - Comparison Matrices
  - Time-of-day distributions

Calvert Cliffs Data

- Obtained from single tower, with instruments at 10m and 60m
- However, I used “raw” data categorized by Safety Guide 23 guidance... I had to process data

Agreement Graph

Calvert Delta-T:Lower Sigma Theta

60-m Delta-T vs. 10-m Sigma

Agreement Graph

Calvert Delta-T:Upper Sigma Theta

60-m Delta-T vs. 60-m Sigma
Agreement Graph
Calvert Lower Sigma Theta:Upper Sigma Theta
10-m Sigma vs. 60-m Sigma

Class A Hour Distribution
Calvert Cliffs
Class A Stability vs. Time of Day

Class G Hour Distribution
Calvert Cliffs
Class G Stability vs. Time of Day

Nine Mile Point Data
- Obtained from single tower, with instruments at 30ft, 100ft, and 200ft
- 15-min averages for 2-year period: 2001, 2002, yielded ~70,000 observations
- Used ‘processed’ 15-minute stability class data categorized by Safety Guide 23 guidance... I used what Nine Mile provided

Stability Class Frequencies
Nine Mile Point
Stability Class Frequencies

Agreement Graph
Nine Mile Lower Delta-T:Upper Delta-T
100-ft Delta-T vs. 200-ft Delta-T
Agreement Graph
Nine Mile Middle Sigma Theta:Upper Delta-T
100-ft Sigma vs. 200-ft Delta-T

Agreement Graph
Nine Mile Upper Sigma Theta:Lower Delta-T
200-ft Sigma vs. 100-ft Delta-T

Agreement Graph
Nine Mile Upper Sigma Theta:Upper Delta-T
200-ft Sigma vs. 200-ft Delta-T

Class A Hour Distribution
Nine Mile Point: Delta-T Data
Class A Frequency vs. Time of Day

Class G Hour Distribution
Nine Mile Point: Delta-T Data
Class G Frequency vs. Time of Day
Summary

- Stability classes derived from delta-T do not compare well with those derived from sigma theta method... limited applicability for substitution
- Measurements at the top of the tower (delta-T and/or sigma theta) tend to yield higher stability classes

Summary – continued

- Stability classes derived from delta-T show a higher dependence on time of day... due to solar heating of the ground
- All three plants had a higher than expected frequency of class A compared to other stability classes... coastal phenomenon?

Concerns - I

- If primary source of stability class is lost, is using an alternate source that could yield a stability class that is different by 2 or more classes appropriate?
- Especially of concern if primary source is delta-T, and backup is sigma theta from a short tower.
  - However, consider –
    - Any local data is better than remote data
    - Most remote sources of data (airport, NWS) are not equipped to provide information for derivation of stability class

Concerns - II

- Is it appropriate to extrapolate stability class from a given level of a tower to a different level of a release point?
  - Consider –
    - Stability class measured at a given level of a tower reflects conditions at that level
    - Need to match level of measurement with level of release point as much as practicable
    - Delta-T reflects vertical mixing, whereas sigma theta reflects horizontal mixing... both are needed in X/Q determination, but seldom independently measured and simultaneously applied
Concerns - III

- Which method is better... delta-T or sigma theta?
- Consider –
  - Safety guide 23 references both methods, so either is appropriate for regulatory compliance... does the NRC have a preference?
  - You may want to perform your own evaluation or comparison so that you are familiar with the specifics at your site, are comfortable with any differences, and understand enough to defend your approach.