Introducing Continuum Surface Roughness Wind Flow Model:

Summary of Impact on Model Accuracy at Eleven Project Sites

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Introduction

In the first version of Continuum, released in January 2015, one of the model assumptions was that the surface roughness was approximately uniform and that only variations in the terrain would have an effect on the wind speed. While this assumption may be valid in some situations, there are many instances when the surface roughness is not constant and should be considered in the wind flow model.

In Continuum 2.0, a surface roughness model has been implemented and is based on the log law shear profile. In this new version, land cover data is imported and is converted to surface roughness and displacement height. To estimate the wind speed across a project area, the variations in the surface roughness and displacement height are analyzed and their influence on the wind speed are estimated.

To test the relative effect of applying the surface roughness model, a validation study was conducted at eleven project sites across the U.S. At each site, the number of met sites varied from four to eleven and, at each site, two Continuum wind flow models were generated: one with the surface roughness model applied and one ignoring the surface roughness. The following summary report presents the results of this ‘before and after’ study.

Summary of Continuum Model Accuracy at Eleven Sites: Before and After Surface Roughness Model Applied

To compare the models and to test the robustness of each, two analyses were performed at each site. First, the root-mean-square (RMS) error of the met site cross-predictions generated from the site-calibrated Continuum model are compared. These errors represent how well the met sites are able to cross-predict one another after the site-calibration is complete.

Secondly, at each site, a Round Robin (or ‘Leave One Out’) analysis was performed where each met site was systematically omitted from the model and then the wind speed was estimated at that excluded site. The Round Robin analysis demonstrates how robust the model is and whether the model is over-fitting to the data.
In the Table 1 and Figure 1 below, the RMS of the met site cross-prediction errors are compared between the two models which show the ‘before and after’ effect of applying the surface roughness model.

In Table 1, the sites where implementing the surface roughness model resulted in a decrease in cross-prediction error are highlighted in yellow. As shown, on average, the met cross-prediction error dropped from 1.33% to 1.07%; a decrease of ~20%. Eight of the eleven sites showed a drop in the model error when the surface roughness model was applied and the average change in the met cross-prediction RMS error was -25.7%.

Site 8 showed the largest decrease in model error where the RMS error went from 1.67% down to 0.82% which equates to a decrease of 51% in the met cross-prediction RMS error.

**Table 1: Summary of Met Cross-Prediction RMS Error: Before and After Surface Roughness Model Applied**

<table>
<thead>
<tr>
<th>Site</th>
<th>Num. Mets</th>
<th>Surface Roughness NOT Included</th>
<th>Surface Roughness Included</th>
<th>% Change</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>5</td>
<td>0.53%</td>
<td>0.55%</td>
<td>3.6%</td>
</tr>
<tr>
<td>2</td>
<td>8</td>
<td>1.97%</td>
<td>1.45%</td>
<td>-26.0%</td>
</tr>
<tr>
<td>3</td>
<td>4</td>
<td>1.03%</td>
<td>0.74%</td>
<td>-28.7%</td>
</tr>
<tr>
<td>4</td>
<td>6</td>
<td>2.15%</td>
<td>1.40%</td>
<td>-34.8%</td>
</tr>
<tr>
<td>5</td>
<td>11</td>
<td>1.91%</td>
<td>1.68%</td>
<td>-11.8%</td>
</tr>
<tr>
<td>6</td>
<td>8</td>
<td>1.83%</td>
<td>1.57%</td>
<td>-14.3%</td>
</tr>
<tr>
<td>7</td>
<td>4</td>
<td>1.02%</td>
<td>0.85%</td>
<td>-17.2%</td>
</tr>
<tr>
<td>8</td>
<td>8</td>
<td>1.67%</td>
<td>0.82%</td>
<td>-51.0%</td>
</tr>
<tr>
<td>9</td>
<td>7</td>
<td>0.72%</td>
<td>0.79%</td>
<td>10.6%</td>
</tr>
<tr>
<td>10</td>
<td>4</td>
<td>0.80%</td>
<td>0.68%</td>
<td>-14.5%</td>
</tr>
<tr>
<td>11</td>
<td>6</td>
<td>1.06%</td>
<td>1.24%</td>
<td>17.5%</td>
</tr>
<tr>
<td><strong>Average</strong></td>
<td><strong>1.33%</strong></td>
<td><strong>1.07%</strong></td>
<td></td>
<td><strong>-19.8%</strong></td>
</tr>
</tbody>
</table>

**Sites with error decreased**

| Average | 1.55% | 1.15% | -25.7% |
Next, in Table 2 and Figure 2, the results of the Round Robin analysis are presented for each site and compare the error of the model that included the surface roughness model to the model that omitted this feature. The sites where a decrease in the Round Robin error was observed are highlighted in yellow. Seven of the eleven sites showed a drop in the error when the surface roughness model was applied, one was relatively unchanged and two sites showed an increase in the Round Robin error.

On average, the Round Robin error decreased from 1.90% to 1.65% which is a decrease of 13%. When only considering the sites where a drop in the Round Robin error was observed, the average error decreased from 2.45% to 1.91%; a change of -21.9%.

Similar to the met cross-prediction error comparison, the site that saw the largest decrease in error was Site 8 where the Round Robin error changed from 2.11% down to 1.36% which works out to a difference of -35.7%.
Table 2: Summary of Round Robin (‘Leave One Out’) RMS Error: 
Before & After Surface Roughness Model Applied

<table>
<thead>
<tr>
<th>Site</th>
<th>Num. Mets</th>
<th>Surface Roughness NOT Included</th>
<th>Surface Roughness Included</th>
<th>% Change</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>5</td>
<td>0.52%</td>
<td>1.20%</td>
<td>131.4%</td>
</tr>
<tr>
<td>2</td>
<td>8</td>
<td>1.85%</td>
<td>1.23%</td>
<td>-33.4%</td>
</tr>
<tr>
<td>3</td>
<td>4</td>
<td>1.78%</td>
<td>1.71%</td>
<td>-4.1%</td>
</tr>
<tr>
<td>4</td>
<td>6</td>
<td>2.58%</td>
<td>1.82%</td>
<td>-29.3%</td>
</tr>
<tr>
<td>5</td>
<td>11</td>
<td>1.69%</td>
<td>1.58%</td>
<td>-6.4%</td>
</tr>
<tr>
<td>6</td>
<td>8</td>
<td>2.77%</td>
<td>2.62%</td>
<td>-5.5%</td>
</tr>
<tr>
<td>7</td>
<td>4</td>
<td>4.35%</td>
<td>3.05%</td>
<td>-29.8%</td>
</tr>
<tr>
<td>8</td>
<td>8</td>
<td>2.11%</td>
<td>1.36%</td>
<td>-35.7%</td>
</tr>
<tr>
<td>9</td>
<td>7</td>
<td>0.76%</td>
<td>0.83%</td>
<td>9.5%</td>
</tr>
<tr>
<td>10</td>
<td>4</td>
<td>1.41%</td>
<td>1.47%</td>
<td>4.5%</td>
</tr>
<tr>
<td>11</td>
<td>6</td>
<td>1.06%</td>
<td>1.24%</td>
<td>17.5%</td>
</tr>
<tr>
<td><strong>Average</strong></td>
<td><strong>1.90%</strong></td>
<td><strong>1.65%</strong></td>
<td></td>
<td><strong>-13.2%</strong></td>
</tr>
</tbody>
</table>

Sites with error decreased

| Average | 2.45% | 1.91% | -21.9% |

![Round Robin RMS Error: Before & After Applying Surface Roughness model](image)

Model Results at Each Project Site

In the following section, the met cross-prediction error and results of the Round Robin analysis conducted at each of the eleven sites are presented. A histogram of the met cross-predictions are shown for models both with and without the surface roughness model applied. There is also a bar plot which shows the change in the Round Robin estimate error when the surface roughness model was applied. On each plot, a text box presents the RMS error of the estimates for both models.
Model Results for Site 1

Number of Met Sites = 5
Model Results for Site 2

Number of Met Sites = 7

Site 2: Distribution of Met Cross-Prediction Error: With and Without Surface Roughness Model

RMS NO SR: 1.97%
RMS WITH SR: 1.45%

Site 2: Round Robin ("Leave One Out") Estimate Error

RMS NO SR: 1.85%
RMS WITH SR: 1.23%
Model Results for Site 3

Number of Met Sites = 4

Site 3: Distribution of Met Cross-Prediction Error: With and Without Surface Roughness Model

RMS NO SR: 1.03%
RMS WITH SR: 0.74%

Site 3: Round Robin ("Leave One Out") Estimate Error

RMS NO SR: 1.78%
RMS WITH SR: 1.71%
Model Results for Site 4

Number of Met Sites = 6

Site 4: Distribution of Met Cross-Prediction Error: With and Without Surface Roughness Model

- RMS NO SR: 2.15%
- RMS WITH SR: 1.40%

Site 4: Round Robin ("Leave One Out") Estimate Error

- RMS NO SR: 2.58%
- RMS WITH SR: 1.82%
Model Results for Site 5

Number of Met Sites = 11

Site 5: Distribution of Met Cross-Prediction Error: With and Without Surface Roughness Model

RMS NO SR: 1.91%
RMS WITH SR: 1.68%

Site 5: Round Robin ("Leave One Out") Estimate Error

RMS NO SR: 1.69%
RMS WITH SR: 1.58%
Model Results for Site 6

Number of Met Sites = 7
Model Results for Site 7

Number of Met Sites = 4

Site 7: Distribution of Met Cross-Prediction Error: With and Without Surface Roughness Model

RMS NO SR: 1.02%
RMS WITH SR: 0.85%

Site 7: Round Robin ("Leave One Out") Estimate Error

RMS NO SR: 4.35%
RMS WITH SR: 3.05%
Model Results for Site 8

Number of Met Sites = 8

Site 8: Distribution of Met Cross-Prediction Error: With and Without Surface Roughness Model

- RMS NO SR: 1.67%
- RMS WITH SR: 0.82%

Site 8: Round Robin ("Leave One Out") Estimate Error

- RMS NO SR: 2.11%
- RMS WITH SR: 1.36%
Model Results for Site 9

Number of Met Sites = 7

Site 9: Distribution of Met Cross-Prediction Error: With and Without Surface Roughness Model

RMS NO SR: 0.72%
RMS WITH SR: 0.79%

Site 9: Round Robin ("Leave One Out") Estimate Error

RMS NO SR: 0.76%
RMS WITH SR: 0.83%
Model Results for Site 10

Number of Met Sites = 4
Model Results for Site 11

Number of Met Sites = 6

Site 11: Distribution of Met Cross-Prediction Error: With and Without Surface Roughness Model

- RMS NO SR: 1.06%
- RMS WITH SR: 1.24%

Site 11: Round Robin ("Leave One Out") Estimate Error

- RMS NO SR: 1.40%
- RMS WITH SR: 1.51%
Discussion and Conclusions

The relative effect of implementing the Continuum surface roughness model was tested at eleven sites across the U.S. Two analyses were conducted to compare the effect of the surface roughness model. In the first analysis, the RMS of the met cross-prediction error was compared before and after applying the model. In the second analysis, the RMS error of the Round Robin (‘Leave One Out’) analysis was compared.

For all sites, the average met cross-prediction RMS error decreased from 1.33% to 1.07% and, for the eight sites where a drop in error was observed, the error went from 1.55% down to 1.15% which is a change of -25.7%.

The Round Robin analysis also showed that applying the surface roughness model reduces the model error. Recall that, in the Round Robin analysis, met sites are systematically omitted from the model creation, the remaining met sites are used to generate site-calibrated models and the wind speed is then estimated at the excluded met site.

When the surface roughness model was applied, the average Round Robin RMS error for the eleven project sites dropped from 1.90% to 1.65% and, when only considering the seven sites that saw a drop in error, the average Round Robin RMS error decreased from 2.45% down to 1.91%.

Site 8 saw the largest decrease in model error when the surface roughness model was applied. For the met cross-prediction comparison, the RMS error decreased by approximately 50% and the Round Robin comparison saw the RMS error change from 2.11% to 1.36% which is a significant improvement to the model accuracy.

One of the eleven project sites that was tested saw a slight increase in the model error when the surface roughness model was implemented. Since it is possible for the surface roughness model to be detrimental to the model accuracy, this feature may be disabled in Continuum 2.0. It is recommended to conduct the same type of analysis as shown above to determine whether or not to use the surface roughness model for a particular project site.

The surface roughness can play a significant role in the wind flow model and it has been shown that, by extending the Continuum model to analyze the variations in the surface roughness and displacement height, the model accuracy is significantly improved.