Motivation for this research
AIRPACT-5 forecasts air quality in the Pacific Northwest U.S., including:
- Gas phase chemicals, such as O₃, NOₓ, CO,
- PM₂.₅ (particulate matter < 2.5μm) and PM₁₀ (< 10μm),
- AOD, a measure of sunlight extinction (scattering + absorption) by PM.

The goal of this study is to evaluate AIRPACT-5 model predictions against measurements of air quality taken at the ground level:
- aerosol optical depth (AOD) using sun photometer.
- aerosol scattering coefficient using nephelometer.
- mass concentration of PM₂.₅ and PM₁₀.

This helps us to understand a model’s performance and to find weaknesses of the model.

Why ground based remote sensing?
Satellite-based remote sensing is great for measuring AOD and other aerosol metrics from space, however there are a few drawbacks:
- Polar orbiting satellites may only pass over an area once per daylight period.
- Ground measurements provide a more continuous record.
- Fig. 1 shows that clouds obscure satellite AOD measurement. If there are clouds when the satellite passes overhead, that time’s AOD measurements will be lost.

AERONET ground-based remote sensing network
AERONET (AERosol RObotic NETwork) is a worldwide network of sun photometers (Fig. 2) that detect AOD, which relates to aerosol load in the atmosphere. Validation of AIRPACT (Air Information Report for Public Access and Community Tracking) model AOD predictions against AERONET measurements is a primary goal of this study.

Figure 1. MODIS satellite measurement of AOD on April 22, 2017. The large area of missing data in the AIRPACT domain is from cloud cover interference.

Figure 2. AERONET Cimel CE318 sun photometer. The device follows the sun across the sky.

Figure 3. AERONET sites in North America.

AERONET AOD data uses:
- Multiband wavelength channels. The system detects sun irradiance at wavelengths of 320/380/420/500/675/870/937/1020/1640 nm.
- Cloud screening. A cloud screening algorithm employing several criteria is used to eliminate readings that may be contaminated by cloud cover. The suspect readings are thrown out. We use the cloud screened data here.

The IMPROVE nephelometer network
The IMPROVE (Interagency Monitoring of Protected Visual Environments) program is an outcome of the 1977 Clean Air Act. The program monitors visual air quality via a network of nephelometer instruments, as well as atmospheric mass concentration of gases and PM using automated air sampling instruments. Evaluating AIRPACT AOD against IMPROVE data is a secondary goal of this study.

Methods
- We used the AIRPACT-5 air quality simulations for August 2015, which had unusually high wildfire activity.
- The AERONET data was obtained from the following link: https://aeronet.gsfc.nasa.gov/new_web/aerosols.html. The AERONET data used was version 3, and level 1.5 (cloud screened). We used AOD at 550 nm from AERONET. IMPROVE nephelometer data was from: http://views.cira.colostate.edu/fed/DataWizard/Default.aspx.
- The data was analyzed using Python script. Time series plots (Fig. 7), colormap plots (Fig. 4) and scatter plots (Fig. 5) were used to compare AIRPACT predictions to the observations, and some basic statistics (Table 1) were calculated to evaluate model performance.
- Challenges: Sporadic coverage, both spatial and temporal has been an issue i.e. only 3 IMPROVE sites with nephelometer readings were available in the AIRPACT domain, and the AERONET sites

About AIRPACT-5 AOD calculation:
Aerosol optical depth is computed at a wavelength using the equation below:

\[
\text{AOD} = \sum \left(\sigma_s \cdot \Delta Z_i\right)
\]

where \(\Delta Z_i\) is a height of vertical layer \(i\), \(N\) is the total vertical layers in AIRPACT-5, and \(\sigma_s\) and \(\sigma_a\) are aerosol scattering and absorption coefficients, respectively. AOD is a dimensionless quantity.

About nephelometer-based AOD calculation:
The nephelometer’s scattering coefficient is measured at the surface level and has a unit of \(\text{m}^{-1}\). Based on the relationship above, we computed surface-level AOD using the nephelometer’s scattering coefficient and the AIRPACT-5’s surface layer height (\(\Delta Z_s\)). This reconstructed surface AOD accounts for only scattering, while AIRPACT-5 surface AOD includes absorption as well. Because of this, there is a caveat that we expect the nephelometer-based AOD to be lower than the AOD, which also includes absorption.

Table 1. Statistics for each observation site compared with AIRPACT

<table>
<thead>
<tr>
<th>Site</th>
<th>Fractional Bias</th>
<th>Fractional Error</th>
<th>Normalized Bias</th>
<th>Normalized Error</th>
<th>R²</th>
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<td>AERONET</td>
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<tr>
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<td>0.01</td>
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<tr>
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<td>0.40</td>
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<tr>
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<td>0.05</td>
<td>0.01</td>
<td>0.40</td>
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<tr>
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<td>0.05</td>
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<tr>
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<tr>
<td>Grand Teton N.P.</td>
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<td>0.01</td>
<td>0.40</td>
</tr>
</tbody>
</table>

Conclusions
- The AIRPACT-5 model was successfully evaluated against ground-based AERONET remote sensing observations.
- We find a systematic underprediction in the AIRPACT-5 AOD predictions: surface AOD (Fig. 5b), column AOD (Fig. 5a), and Table 1. This is consistent with surface PM₂.₅ evaluation (Fig. 8). It suggests that the underpredicted surface PM₂.₅ partly contributes to the lower AOD predictions in AIRPACT-5.
- However, the underpredicted AOD in AIRPACT-5 could be also explained by error in the aerosol vertical distribution. August 2015 experienced active wildfires, whose emissions are typically distributed vertically from the surface to a few kilometers. If the model’s wildfire plume height is not realistic, it will affect AOD evaluation. We must have a PM vertical distribution to confirm this.
- Even though we have very few IMPROVE nephelometer sites for this time period, it was very beneficial to include them in this study as it helps to evaluate aerosol vertical distributions (surface vs. total column).
- We find a wide range of the correlation coefficient (R²) at each observation site ranges: 0.6 at IMPROVE’s Grand Teton N.P. to 0.01 at AERONET’s Trinidad Head, with an average R² value of 0.45.