MSFC-2042

Identifying Optimal Temporal Scale for the Correlation of AOD and Ground Measurements of $PM_{2.5}$ to Improve the Model Performance in a Real-time Air Quality Estimation System

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1. INTRODUCTION

Aerosol optical depth (AOD), derived from satellite measurements using Moderate Resolution Imaging Spectrometer (MODIS), offers indirect estimates of particle matter. Research shows a significant positive correlation between satellite-based measurements of AOD and ground-based measurements of particulate matter with aerodynamic diameter less than or equal to 2.5 micrometers ($PM_{2.5}$) (Chu et al., 2005 and Gupta et al., 2006). In addition, satellite observations have also ~~been~~ shown great promise in improving estimates of $PM_{2.5}$ air quality surface (Gupta et al, 2006; ~~and~~ Kumar et al., 2007; Al-Hamdan et al., 2008). Research shows that correlations between AOD and ground $PM_{2.5}$ are affected by a combination of many factors such as inherent characteristics of satellite observations, terrain, cloud cover, height of the ~~missing~~ mixing layer, and weather conditions (Kumar et.al., 2007, Gupta et al., 2006), and thus might vary widely in different regions, different seasons, and even different days in a same location. Analysis of correlating AOD with ground measured $PM_{2.5}$ on a day-to-day basis suggests the temporal scale, a number of immediate latest days for a given run's day, for their correlations needs to be considered to improve air quality surface estimates, especially when satellite observations are used in a real-time pollution system. The second reason is that correlation coefficients between AOD and ground $PM_{2.5}$ cannot be predetermined and needs to be calculated for each day's run for a real-time system because the coefficients can vary over space and time. Few studies have been conducted to explore the optimal way to apply AOD data to improve model accuracies of $PM_{2.5}$ surface estimation in a real-time air quality system. We believe that two major aspects may be worth consideration when applying satellite data to improve the performance of pollution surface models: 1) the approach to integrate satellite measurements with ground measurements for the pollution estimation, and 2) identify an optimal temporal scale for calculating the correlation of AOD and ground measurements. This paper will focus on the second issue and discuss the best temporal scale to calculate the correlation of AOD and ground particle matter data to improve the results of pollution models in a real-time system.

2. Real-TIME $PM_{2.5}$ ESTIMATION SYSTEM

The real-time $PM_{2.5}$ estimation system in this paper is ~~improved~~ built from a $PM_{2.5}$ surface model, -originally developed by NASA Marshall Space Flight Center (MSFC) (Al-Hamdan et al., 2008), in order to be integrated with a real-time geo-spatial health surveillance system developed at University of Mississippi Medical Center. The ~~improved~~ model estimates daily average $PM_{2.5}$ ~~PM2.5~~ concentration for Mississippi and its neighboring states using NASA MODIS AOD data on board Terra and Aqua and EPA ground measurements from the AirNow gateway system which runs in a batch mode on a daily basis. The model uses the same spatial resolution as that of satellite data as its grid surface outputs (10*10 km). The system includes the following three main components: 1) AOD-$PM_{2.5}$ linear regression models for AOD-derived $PM_{2.5}$, 2) a surface model to interpolate AOD-derived $PM_{2.5}$ ~~PM2.5~~ and ground measurements of $PM_{2.5}$ to a continuous grid surface respectively, 3) an approach to integrate the two interpolated surfaces above into a final surface output if a significant relationship is found between them on each calculated day, otherwise only ground measurements are used for the model output. The model domain is shown in Figure 1.

Figure 1. Model domain for the air quality system

3. METHODOLOGY

To identify the optimal temporal scale for the AOD-$PM_{2.5}$ correlations, we chose the following five different temporal scales to evaluate their impact on the performance of the daily-basis pollution surface models in both 2004 and 2005: 1) within the last three days, 2) within the last ten days, 3) within the last thirty days, 4) within the last ninety days, and 5) the time period with the highest correlation in a year (August-October in 2004 and June-September in 2005). For the first four temporal scales, the regression analysis was done on the fly to determine the significant relationship between AOD and $PM_{2.5}$ based on the p-value on each model running day by utilizing the ground data from each monitoring station inside the study area and its corresponding average MODIS AOD within one degree range of a station. When the p-value is less than or equal to 0.05, their relationship is considered significantly, AOD data are determined to be used in the model. As to the last temporal scale, a predetermined regression model is used for the model estimation in the defined time period in each evaluating year.

To make the accuracy assessment subjectively, a station site (Site ID: 280810005 its location seen in Figure1) was ~~leaved~~ left out in the air quality estimation and was only used for the performance evaluation. The model performance is evaluated for its accuracy, bias, and errors based on the following selected statistics: the Mean Bias (MB), the Normalized Mean Bias (NMB), the Root Mean Square Error (RMSE), Normalized Mean Error (MNE), and the I~~i~~ndex of A~~a~~greement (IOA). They are defined below:

$$MB = \frac{1}{N}\sum_{1}^{N}(C_{m-}C_{o}) \tag{1}$$

$$NMB = \sum_{1}^{N}(C_m - C_o) / \sum_{1}^{N} C_o 100\% \tag{2}$$

$$RMSE = \sqrt{\frac{1}{N}\sum_{1}^{N}(C_m - C_o)^2} \tag{3}$$

$$MNE = \sum_{1}^{N} | C_m - C_o | / \sum_{1}^{N} C_o 100\% \tag{4}$$

$$IOA = 1 - \sum_{1}^{N}(C_m - C_o)^2 / \sum_{1}^{N}(| C_o - \overline{C}_o | + | C_m - \overline{C}_o |)^2 \tag{5}$$

Where C_m and C_o are modeled and observed values, respectively. $\overline{C}_o$ is the average observed value with the sample size N.

4. RESULTS

The results of the model performance for each evaluating temporal scale are displayed in Table 1 and Figure 2. Surprisingly, the models with the last three days and last 10 days temporal scales showed the highest biases (MB and NMB), consistently in both 2004 and 2005. The model with the temporal scale of last three days also had the highest errors (RMSE and MNE) in both 2004 and 2005, and thus was believed to have the worst model performance by looking at those calculated statistics indexes. Its IOA value, the lowest among the five chosen temporal scales, also supports this conclusion. The model with the fifth temporal scale had higher biases (MB and NMB) in both 2004 and 2005. This result is reasonable because it only used satellite observations in the predefined time period and failed to use those observations having significant correlation with ground measurements outside the predefined time period, thus it is not a good strategy on utilizing satellite data for building a model.

The third model with the temporal scale of last 30 days had higher model biases than ~~that did~~ the fourth model with the temporal scale of last 90 days, whereas it had lower model errors in 2004. But, the IOA index ~~might~~ suggests that the fourth model might have better performance in 2004. However, these two models showed reverse performance patterns in 2005. The thrid model had the same biases and IOA as ~~that did~~ those of the fourth model, but the third model had higher model errors. Thus, it is difficult to judge and compare the performance of these two models by just looking at those statistical indexes.

Table 1. Accuracy assessment of the air quality models using different temporal scales for AOD-$PM_{2.5}$ correlations

Year	Temporal scales (previous days)	MB	NMB	RMSE	MNE	IOA
2004	3	-0.172	-1.33	3.68	19.70	0.906
	10	-0.137	-1.07	3.68	19.70	0.906
	30	-0.104	-0.81	3.65	19.60	0.908
	90	-0.090	-0.70	3.68	19.70	0.907
	Season with highest correlation	-0.148	-1.15	3.65	19.50	0.908
2005	3	-0.068	-0.49	3.52	17.90	0.943
	10	-0.032	-0.23	3.50	17.70	0.944
	30	0.007	0.05	3.50	17.90	0.944
	90	-0.007	-0.05	3.47	17.80	0.944
	Season with highest correlation	-0.031	-0.22	3.51	17.90	0.943

A key factor possibly impacting the performance of these models is the correlation coefficients of AOD and ground $PM_{2.5}$ calculated in each model run's day. Better correlation coefficients will certainly improve the model performance, whereas poorer correlation coefficients will degrade the model performance. To analyze and check their correlation coefficients, a histogram of R-Squared values of AOD and ground measurements of $PM_{2.5}$ for each evaluated model except the fifth model in 2004 and 2005 is displayed in Figure 3. It clearly shows that the first and second temporal scales have the least days with significant correlation between satellite observations and ground data in each year. Moreover, their R-Squared values are also lower generally in 2004 and 2005 compared to other models with different temporal scales. This fact tells that the short temporal scale is not a good choice to determine the correlation of satellite and ground observations. As we have mentioned, their correlation is affected by many factors such as weather conditions. One possible reason is that the correlations in short temporal scales contain more noises because of impacts by other factors such as weather conditions. When longer temporal scale is used for the correlations, those noises might be smoothed by the time factor, and thus the correlation may have better quality. This explains why the short temporal scale is not a good choice in the model construction. However, if the temporal scale is too long, the correlation might be over smoothed by the time factor, and thus it will not reflect their real relationship in a specific short time period. It might explain why the model with the temporal scale of 30 days had higher IOA value than that with the 90 days temporal scale in 2004.

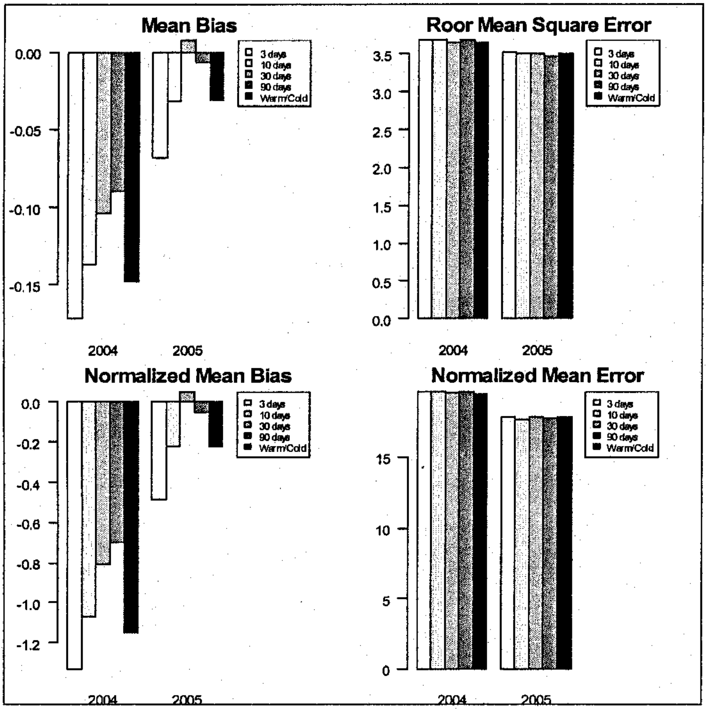

Figure 2. The model performance with five temporal scales for the correlation of AOD and ground measurements of $PM_{2.5}$ in 2004 and 2005

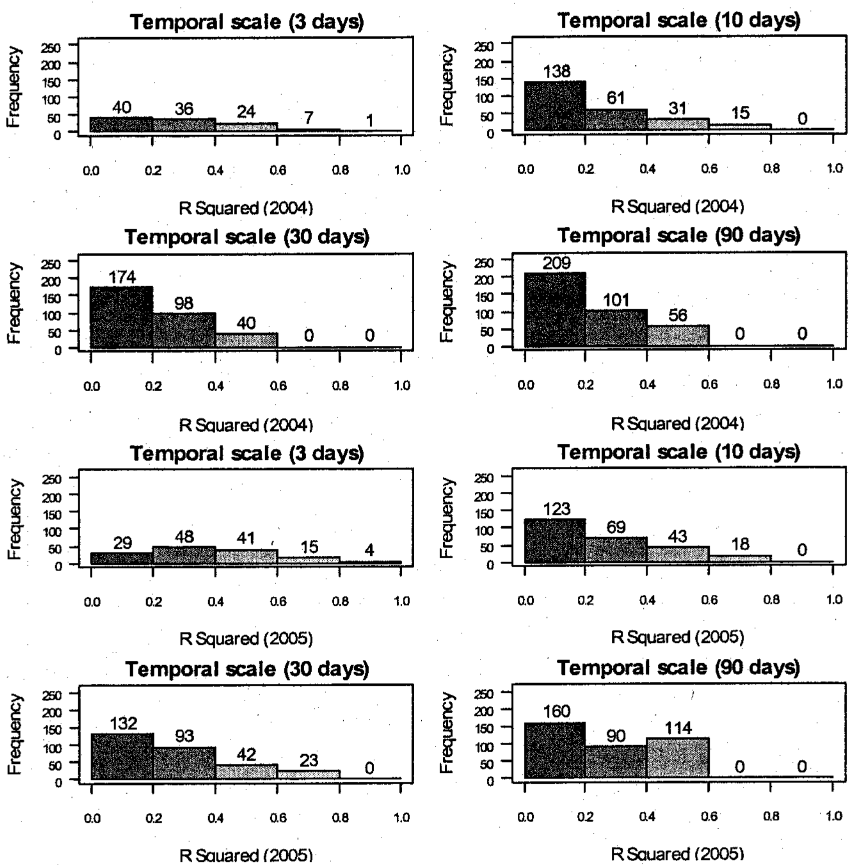

Figure 3. The histogram of R-Squared values of AOD and ground measurements of $PM_{2.5}$ with five different temporal scales in 2004 and 2005.

5.1 Impact of data fusion on the model performance

The five selected statistics of the model performance only show slight differences among the five evaluated temporal scales for the correlation of AOD and ground truth, especially RMSE and NME. The reason is not because the temporal scales of the correlation have not much impact on the model performance but because the weight of satellite observations was only given 10% compared with the weight of ground data given 90% when integrating two interpolated surfaces of satellite observations and ground data into the model output, and therefore the major contribution of the model outcome comes from the ground truth. Consequently, it is reasonable to believe that the slight difference of the selected statistics still truly represents the impact of the temporal scales on the model performance, therefore the conclusion is reliable. Although this paper does not cover the topic of the integration approach of these two data sets (satellite and ground data), it might be worth pointing out their weight should be dependent on their correlation instead of a prefixed value, which needs further research in the future.

5.2 Optimal Temporal scale for the correlation of AOD and ground data

This research shows the optimal temporal scale for the correlation of AOD and ground data might be the latest 30 days among the five chosen temporal scales in the study area. Therefore, it is believed that it is also a good approach to use linear regression models, determined on a monthly basis, for estimating particular matter in the models. However, the finding in this study area might not ~~be able to~~ apply to other areas considering the multiple factors ~~having~~ that influence ~~on~~ the correlation of AOD and ground measurements of $PM_{2.5}$~~PM2.5~~ and their variation over space and time. ~~This will be an interesting to do~~ ~~S~~similar research in other areas will be interesting to do in the future.

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5.3 Areas to improve~~ment~~

Previous research shows that the effect of weather conditions, such as wind velocity, relative humidity, temperature, and atmospheric pressure, can confound the AOD- $PM_{2.5}$~~PM2.5~~ association (Kumar et al, 2007). However, the identified optimal temporal scale in this study did not consider this impact from weather conditions, and thus it is not clear what kinds of impact the weather factors might have on our conclusion. Future study to incorporate other factors such as the weather conditions to determine the optimal temporal scale is likely to answer this important question, and might improve the model performance through a better strategy on using satellite observations.

6. SUMMARY

This research shows that the model with the temporal scale ~~on~~ of the latest 30 days displays the best model performance, thus it is believed the best strategy to utilize satellite observations to improve estimation of particle matter in the study area. ~~It~~ We also need~~s~~ to point out that this conclusion is not considering the confounding impact of weather conditions on their association. It will be a valuable study to incorporate these weather conditions for the optimal temporal scale in ~~the~~ future research.

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