Combining Multi-Wavelength AERONET SSA Retrievals with a MIE Model and UV AI from OMI to Quantify the Global AAOD of BC and OC

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Abstract

Black carbon (BC), organic carbon (OC) and dust (or Absorbing Aerosols - AA) strongly absorb visible solar radiation, leading to impacts on the atmospheric radiation budget, climate, water cycle, and more. Recent attempts have been made to elucidate the spatial-temporal concentrations and radiative forcing of AA over East Asia using the UV band OMAERUV product from OMI. The product provides global coverage of AAOD in the UV bands, limiting the results to where retrievals can be made, and to cases where the average aerosol size is not too small. For these reasons, this approach cannot estimate the magnitude of total AAOD and/or radiative forcing. To achieve this, we include relevant data from multiple bands in the visible and NIR in tandem with the UV, so that a more complete relationship can be made to understand the magnitude and properties of AA globally. We employ a MIE model to simulate the absorption of core-shell coated mixtures of AA (specifically a mixture of BC core with sulfate shell (MBS) and OC core with sulfate shell (MOS) across multiple individual wavelengths. These values are then merged with individual inversions of SSA from AERONET at each individual wavelength across the spectrum from the UV through the NIR. Fitting is done based on the temporally varying magnitude band of the measured AOD and the inverted SSA incorporating all individual data points where both calculations exist at each station, from 2010 to 2016. The relationship between core and shell sizes that is consistent with AERONET is then fitted to OMI measurements that overlap AERONET in space and time. A sensitivity matrix of optical uncertainties is made to compute the robustness of the constrained aerosol size, chemical composition and refractive indices. Initial results show that retrieved aerosol properties of MBS and MOS are consistent with known properties over urban areas, biomass burning areas, and those regions frequently impacted by long-range transport events, as observed over Asia. A few interesting scientific findings include mixing between these different sources and detection of otherwise missing sources. It is hoped that ongoing calculations allowing our approximation to be extended spatially away from sites where AERONET measurements exist will also be ready to present.

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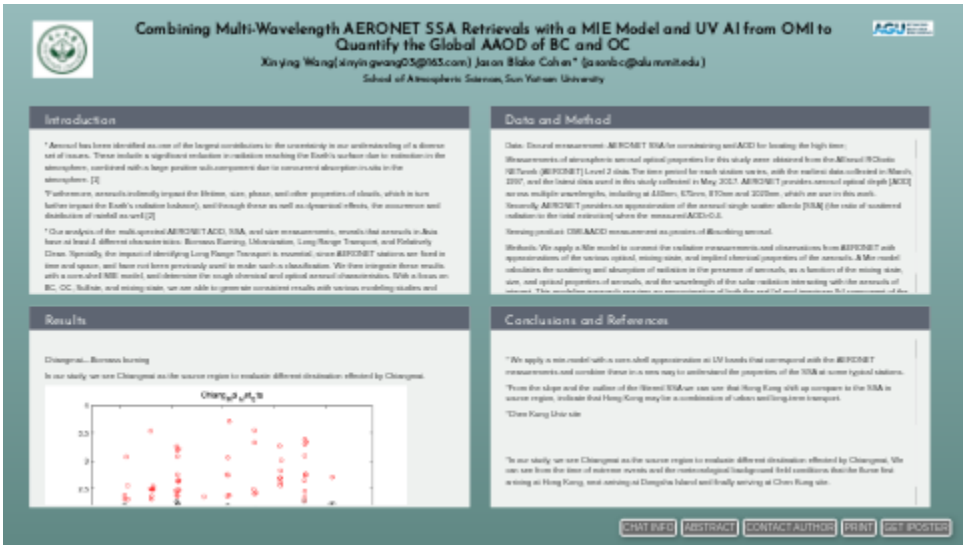

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INTRODUCTION

*Aerosol has been identified as one of the largest contributors to the uncertainty in our understanding of a diverse set of environmental, atmospheric, and climatological issues. These include a significant reduction in radiation reaching the Earth's surface due to extinction in the atmosphere, combined with a large positive sub-component due to concurrent absorption in-situ in the atmosphere. [1]

*These radiative properties of aerosols both directly and indirectly, in connection with physical properties of the aerosols surface and chemical characteristics impact the lifetime, size, phase, and other properties of clouds. These changes in clouds in turn further impact the Earth's radiative balance. Furthermore, these directly and indirectly induced changes (including dynamics) effect the occurrence and distribution of rainfall as well.[2]

*Our work incorporates multi-spectral measurements from AERONET including AOD, SSA, and size measurements, in connection with a variance maximization approach to reveal properties of aersols in Asia. In specific, we find that aerosols in Asia have at least 4 different net characteristics: those relating to Biomass Burning, Urban sources, those which have undergone significant Long Range Transport, and those which come from otherwise relatively clean environments. In specific the ability to identify and classify Long Range Transport is both new and an essential advance, not previously done using AERONET data, which while of high quality, remains fixed in time and space.

*These results are compared with calculations from a core-shell MIE model, and determine the rough chemical, size, and optical aerosol characteristics of the aerosols under each of these different classifications. We specifically focus on the size of BC, the sum of Sulfate and Nitrate, and mixing state, and find that we are able to generate consistent results with various modeling studies and independent measurements. The results conform very well over regions that are known to be heavily polluted, both in terms of urban, biomass burning, and mixed sources.

RESULTS

To ensure that we are focusing on those time periods which are highly polluted, we apply an iterative filter based on statistics of the AERONET measurements of mean AOD and SSA. We define the peaks by iteratively separating the data greater than mean plus one standard deviation from the remaining data, and re-iterating(https://iopscience.iop.org/article/10.1088/1748-9326/abd502 (https://iopscience.iop.org/article/10.1088/1748-9326/abd502)). After this filtering has been performed, We plot the resulting filtered SSA distribution as well as the overall SSA distribution. This difference leads to a case where the mixing state, size, and optical characteristics might be different.

1.Chiangmai---Biomass burning

Based on previous work[3][4][5] (https://doi.org/10.1088/1748-9326/abaa7a (http://dx.doi.org/10.1088/1748-9326/abaa7a) ; https://doi.org/10.5194/acp-20-15401-2020 (https://doi.org/10.5194/acp-20-15401-2020) ; https://acp.copernicus.org/articles/17/721/2017/ (https://acp.copernicus.org/articles/17/721/2017/)), we seriously consider using Chiangmai as the basis set for biomass burning. In order to validate this with our new approach, we first determine the period of high AOD by using our iterative approach in connection with the AERONET UV AOD at 340nm, as observed in Figure 1.

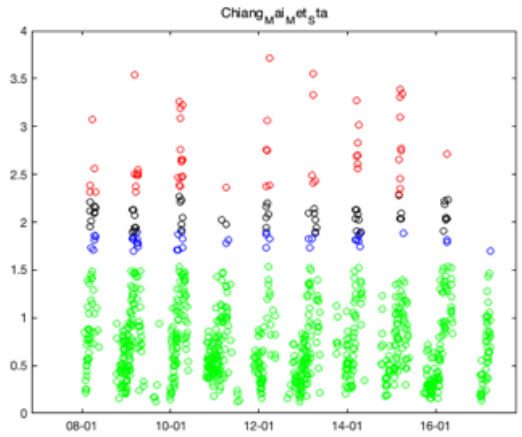

Figure 1: Time series of AERONET AOD at 340nm in Chiangmai
site, red, blue, black, red represent AOD inaverage add one standard deviation, double standard deviation and triple standard deviation

Given this approach, we find that the peak always occurs during roughly the same time (from 13 February through 19 April) every year for 10 years. We also find that the peak never occurs outside of this time. Given this and the previous works identified above, we feel confident in our choice that Chiangmai is the most representative reigion of biomass burning.

As such, from plot the intersection between the measured SSA values at Chiangmai and the MIE model computed SSA, as given in Figure 2.

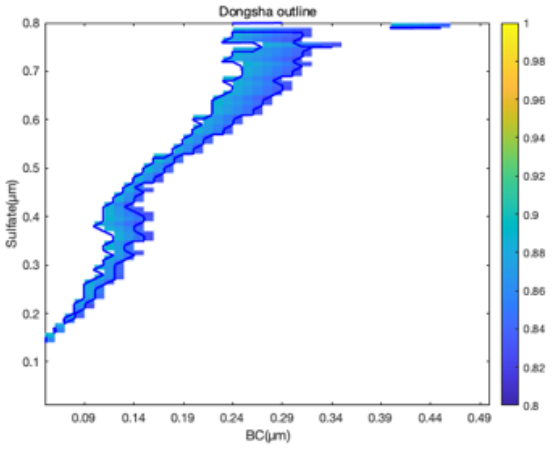

Figure 2: Distribtion of SSA in Chiangmai site in high pollution time.(Length of the polluted time is defined by Fig.1)

This final result will be used as the basis of comparison to determine the fraction of biomass burning found at other sites.

2.Taihu: Urban

Taihu is located in the middle of the Shanghai, Nanjing, Hangzhou urban triangle in lower Jiangsu Province of China, in a city with the third highest per capita income in China. This region has a huge amount of individual vehicles, factories, and other economic activity. As such, it is quite representative of a region in which the major source of pollution is urban. A time series of the AOD including the high times values, which are found to occur quite randomly throughout the dataset are given in Figure 3.

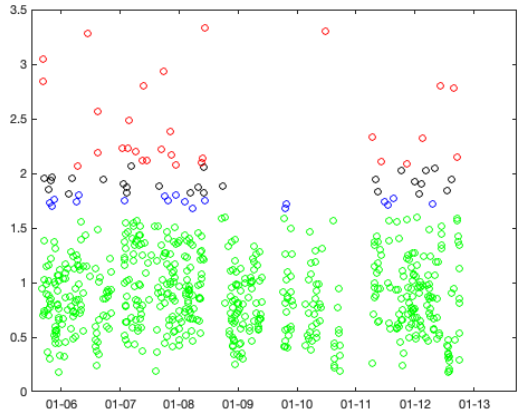

Figure 3: Time series of AERONET AOD at 340nm in
Taihu,WuXi,China site, red, blue, black, red represent AOD inaverage add one standard deviation, double standard deviation and triple

Similar to the case of Chiangmai, we use the measured SSA from the Taihu AERONET site to select which corresponding size pairs of aerosols as computed from the MIE model correspond to Taihu, as given in Figure 4. From this point forward, we use the Taihu outline as representative of urban conditions throughout this work.

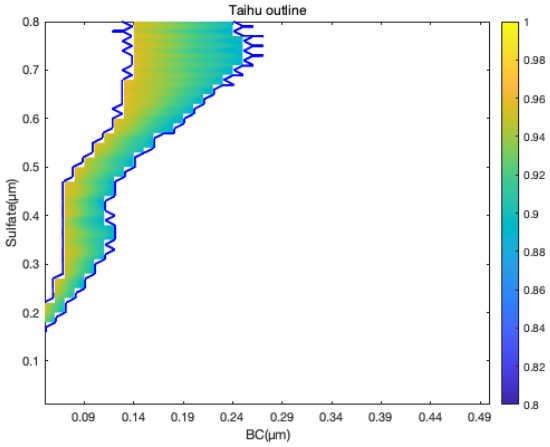

Figure 4: Distribtion of SSA in Chiangmai site in high pollution time.(Length of the polluted time is defined by Fig.3)

3.Long-range transport:

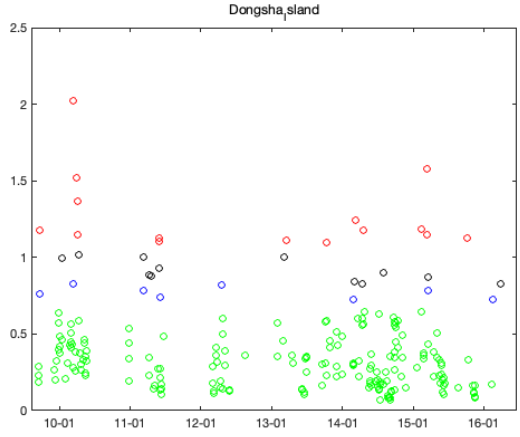

Figure 5: Time series of AERONET AOD at 340nm in Dongsha Island,China site, red, blue, black, red represent AOD inaverage add one standard deviation, double standard deviation and triple stand

We will later use the Dongsha Island outline in high time as an example of Long-range transport to make the comparsion with other sites.

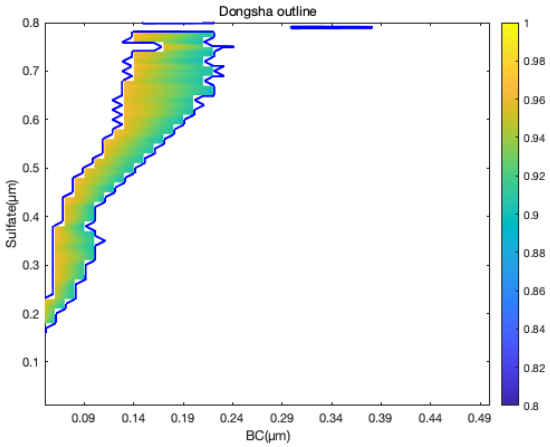

Figure 6: Distribtion of SSA in Chiangmai site in high pollution time.(Length of the polluted time is defined by Fig.5)

Compare to the Taihu and the Chiangmai site, the outline of Dongsha Island is more sharp. Showing a signal of the growth of BC.

Case1:Hong Kong (Mixture of Aerosol Types)

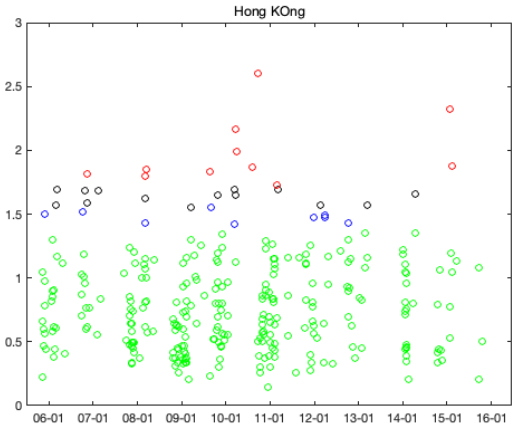

Figure 7: Time series of AERONET AOD at 340nm in Hong Kong,China site, red, blue, black, red represent AOD inaverage add one standard deviation, double standard deviation and triple standa

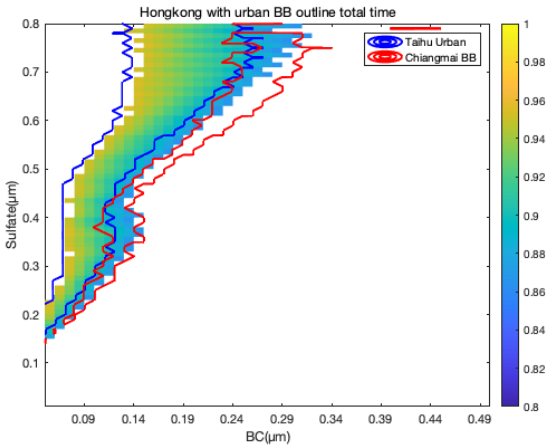

Figure 8: Distribution of SSA in Hong Kong in total time scale with urban and biomass burning outlines.

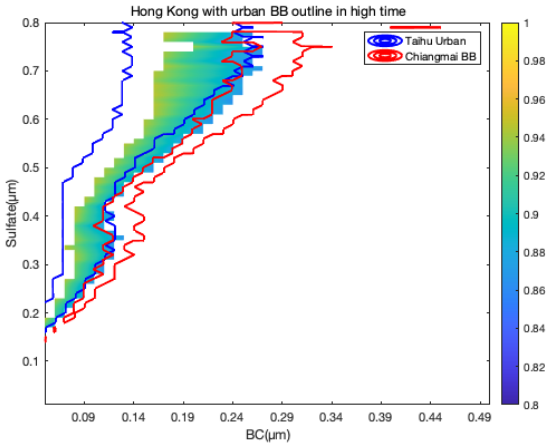

Figure 9: Distribution of SSA in Hong Kong in high time with urban and biomass burning outlines.

Case 2: Chen Kung Univ (Mixed Aerosol Types)

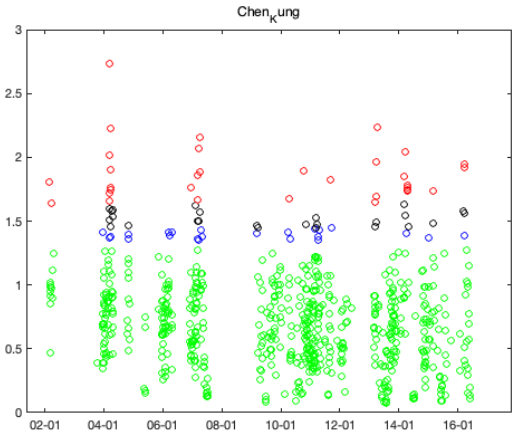

Figure 10: Time series of AERONET AOD at 340nm in Chen Kung Univ,
China site, red, blue, black, red represent AOD inaverage add one standard deviation, double standard deviation and triple standard de

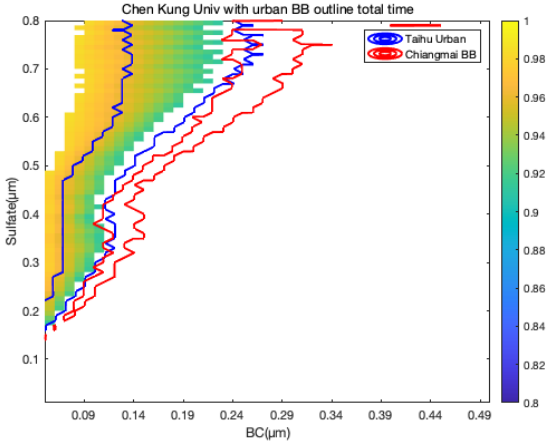

Figure 11: Distribution of SSA in Chen Kung in total time scale with urban and biomass burning outlines.

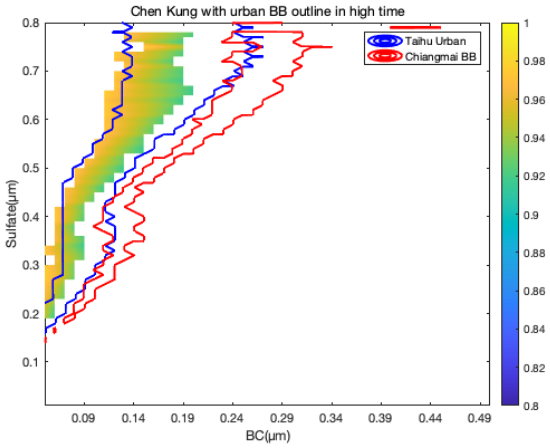

Figure 11: Distribution of SSA in Chen Kung in high time with urban and biomass burning outlines.

Case 3: Singapore (Mixture of Aerosol Types)

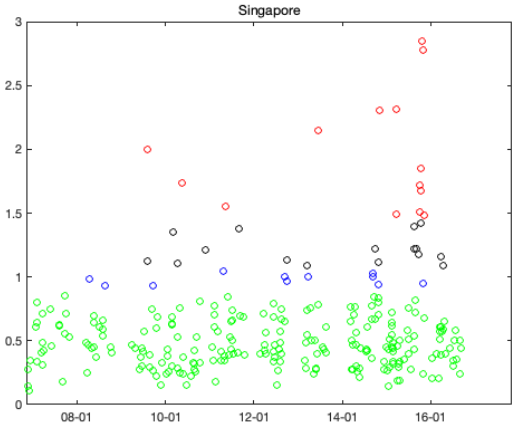

Figure 12: Time series of AERONET AOD at 340nm in
Singapore site, red, blue, black, red represent AOD inaverage add one standard deviation, double standard deviation and triple standar

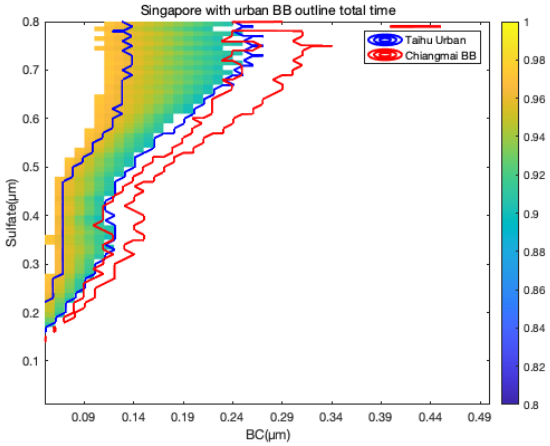

Figure 13: Distribution of SSA in Singapore in total time scale with urban and biomass burning outlines.

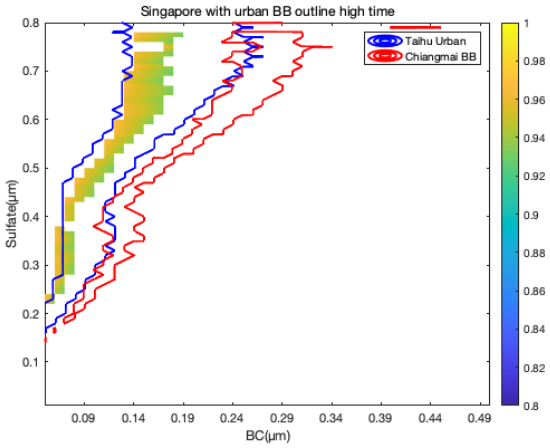

Figure 14: Distribution of SSA in Singapore in high time with urban and biomass burning outlines.

DATA AND METHOD

Data: Measurements of atmospheric aerosol optical properties for this study were obtained from the AErosol RObotic NETwork (AERONET) Level 2 data.The time period for each station varies, with the earliest data collected in March, 1997, and the latest data used in this study collected in May, 2017. AERONET provides aerosol optical depth [AOD] across multiple wavelengths, including at 440nm, 675nm, 870nm and 1020nm, which we use in this work. Secondly, AERONET provides an approximation of the aerosol single scatter albedo [SSA] (the ratio of scattered radiation to the total extinction) when the measured AOD>0.4.

Methods: We apply a Mie model to connect the radiative measurements and observations from AERONET with approximations of the various optical, mixing state, and implied chemical properties of the aerosols. A Mie model calculates the scattering and absorption of radiation in the presence of aerosols, as a function of the mixing state, size, and optical properties of aerosols, and the wavelength of the solar radiation interacting with the aerosols of interest. This modeling approach requires an approximation of both the real [a] and imaginary [b] component of the aerosol's scattering, represented as: m=a+bi.

CONCLUSIONS AND REFERENCES

*1.We successfully use a new analytical approach in combination with AERONET data of AOD and SSA to classify each site into urban, biomass burning, long range transport, and mixed sources. These results are compared with calculations from a core-shell MIE model, and determine the rough chemical, size, and optical aerosol characteristics of the aerosols under each of these different classifications.

*We apply a mie-model with a core-shell approximation at UV bands that correspond with the AERONET measurements and combine these in a new way to understand the properties of the SSA at some typical stations.

*We find that the results of number 2 in terms of aerosol sources: urban, biomass burning, long range transport, and mixed sources are consistent with number 1. We additionally find some surprising and new sources of importance, such as biomass burning having a significant effect in urban Hong Kong, long-range transport having an effect in Taiwan, and biomass burning contributing an important fraction along the Thailand/Malaysia boarder.

[1] Cohen, J. B., Prinn, R. G., & Wang, C. (2011). The impact of detailed urban−scale processing on the composition, distribution, and radiative forcing of anthropogenic aerosols. Geophysical Research Letters, 38(10)

[2]Boucher, O., & Anderson, T. L. (1995). General circulation model assessment of the sensitivity of direct climate forcing by anthropogenic sulfate aerosols to aerosol size and chemistry. Journal of Geophysical Research: Atmospheres, 100(D12), 26117-26134.

[3]Lin C , Cohen J B , Wang S , et al. A new perspective on the spatial, temporal, and vertical distribution of biomass burning: quantifying a significant increase in CO emissions[J]. Environmental Research Letters, 2020, 15(10):104091 (13pp).

[4]Wang shuo, Jason Blake Cohen, Lin Chuyong, Deng Weizhi. Constraining the relationships between aerosol height, aerosol optical depth and total column trace gas measurements using remote sensing and models.

[5]Cohen J B , Lecoeur E , Daniel H L N . Decadal-scale relationship between measurements of aerosols, land-use change, and fire over Southeast Asia[J]. Atmospheric Chemistry and Physics, 2017, 17(1):721-743.

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