

The manuscript presents a revised framework for classifying organic aerosols based on wavelength-dependent absorption properties. By compiling refractive index data from previous studies and translating the proposed IRI thresholds into MAC and SSA space, the authors attempt to provide a practical optical classification scheme for organic aerosols and brown carbon. The topic is relevant to aerosol-radiation interactions, climate-model parameterization, and satellite retrieval applications. The manuscript is generally well structured, and the effort to extend previous BrC classification concepts from a single reference wavelength to a broader spectral range is valuable. However, several issues need to be addressed before the manuscript can be considered for publication.

1. The current classification boundaries appear to be empirically selected from literature data, and additional quantitative evidence is needed to demonstrate their robustness and universality.

Response: *We thank the reviewer for this comment. As the reviewer pointed out, the classification boundaries used in this study are based on the currently available literature data. We acknowledge that the boundary or the threshold value associated with each classification may vary slightly as new studies report updated RI values.*

However, an important consideration is that we classified the organic species based on their chemical, physical, and optical characteristics rather than solely on their RI values. For instance, the S-BrC aerosols include the wi-BrC aerosol that are extracted in the laboratories using solvents and tarballs that are characterized using high energy electron beam techniques. Hence, while future measurements may lead to modest adjustments in the classification boundaries, we do not expect such measurements to vary significantly.

Although, we agree with the reviewer that it is important to make this point clear. Hence, we will add this discussion to the “Caveats and Limitations” section of the paper as follows:

“The classification boundaries presented in this study are based on currently available literature data and may be subject to slight adjustments as additional refractive index measurements become available. However, because the classifications consider the chemical, physical, and optical characteristics of the aerosol species, substantial changes to the overall classification are not expected.”

2. The current framework is derived from a relatively limited number of OA species, and its applicability to the broader diversity of atmospheric organic aerosols remains uncertain.

Response: *The current framework is based on the available literature data for the refractive indices of different OA species. We provide representative species for four absorption categories based on the currently available data. Although numerous studies have characterized the chemical composition of atmospheric organic aerosol species,*

only a limited number of studies have reported their refractive indices. Therefore, the current framework may not capture the full diversity of atmospheric OA, and its applicability may be expanded as additional refractive index measurements become available.

3. Since the refractive index data originate from multiple measurement techniques, the consistency and comparability of these datasets should be addressed.

Response: *We thank the reviewer for this comment. As the reviewer pointed out, the RI data were obtained using multiple measurement techniques, and we have considered this factor in developing our classification framework. For example, tarball species characterized using electron energy loss spectroscopy (EELS) are classified as S-BrC because exposure to a strong electron beam can cause volatile components to evaporate. In contrast, tarballs characterized using a cavity-enhanced system are classified in the M-BrC category, which reflects the presence of both soluble and insoluble BrC components. For the anthropogenic and biogenic species, the refractive indices were obtained using consistent measurement techniques within each category.*

4. Although the manuscript introduces a wavelength-dependent extension of existing BrC/OA classification concepts, related classifications of absorbing and weakly absorbing organic aerosols have been discussed in earlier studies (e.g., <https://doi.org/10.1007/s40726-020-00139-3>; <https://doi.org/10.1002/2013JD019912>; <https://doi.org/10.1029/2007JD009756>). The authors should therefore more clearly identify the unique contribution of the present work and emphasize the added value of incorporating wavelength-dependent optical information into the classification framework.

Response: *As noted by the reviewer, the terminology used for the classification was adapted from previous studies; however, the classification approach presented in our study is novel in several important aspects.*

1. *Wavelength-dependent classification: Our study demonstrates that the classification of organic aerosols strongly depends on the wavelength at which their optical properties are evaluated. We therefore provide a wavelength-dependent classification and recommend optimal wavelengths for distinguishing organic aerosols into the four proposed categories. We also provide wavelength-dependent thresholds for defining each class, which can be applied to measurements or model simulations for calculating radiative effects.*
2. *Integration of physical, chemical, and optical properties: While we demonstrate that IRI is a critical parameter for separating organic species classes, we also provide a framework for assigning mass absorption coefficients (MACs) and single scattering albedo (SSA) values for the same organic classes. This novel contribution provides a direct connection between the proposed optical categories and the organic aerosol species that are present in the atmosphere for model simulations and measurement*

closure studies. These MAC and SSA values are also wavelength dependent. To better highlight these contributions, we have added the following sentence to the manuscript:

We have added the following text into the conclusion section of the manuscript:

“This study builds on previous work to provide another step towards improving measurement-model synergy. Our approach expands current schemes for classifying organic aerosols by considering physical, chemical, and optical properties together. Most importantly, this work provides:

Wavelength-dependent classification: Our study demonstrates that the classification of organic aerosols strongly depends on the wavelength at which their optical properties are evaluated. We therefore provide a wavelength-dependent classification and recommend optimal wavelengths for distinguishing organic aerosols into the four proposed categories. We also provide wavelength-dependent thresholds for defining each class, which can be applied to measurements or model simulations for calculating radiative effects.

Integration of physical, chemical, and optical properties: While we demonstrate that IRI is a critical parameter for separating organic species classes, we also provide a framework for assigning mass absorption coefficients (MACs) and single scattering albedo (SSA) values for the same organic classes. This novel contribution provides a direct connection between the proposed optical categories and the organic aerosol species that are present in the atmosphere for model simulations and measurement closure studies. These MAC and SSA values are also wavelength dependent.”

5. The rationale for adopting wavelength-dependent thresholds should be strengthened. Additional discussion is needed regarding the scientific advantages of multi-wavelength optical characterization relative to traditional single-wavelength approaches.

Response: *We thank the reviewer for this comment. We have added additional discussion to strengthen the need for adopting wavelength-dependent thresholds.*

Older version:

“This study aims to provide clear thresholds accounting for the large variability in OA species so that it can be represented more accurately in climate calculations.”

New version:

“This study provides a novel approach for classifying organic aerosols by accounting for their physical, chemical, and optical properties. The wavelength-dependent classification further provides recommendations for selecting an optimal wavelength to distinguish among different organic aerosol species. Furthermore, several models treat OA as a single species, and often non-absorbing at all wavelengths. But our classification suggests that this will depend on the wavelength used.”

6. The manuscript would benefit from a clearer discussion of how the proposed classification framework could be implemented in aerosol optical databases, satellite retrieval algorithms, and climate model parameterizations.

Response: *We thank the reviewer for this comment. Organic aerosols are commonly represented in climate models using a single particle refractive index or a simplified set of optical properties. Our study demonstrates that organic aerosol species can exhibit a broad range of optical behavior, from highly scattering to strongly absorbing. Therefore, representing organic aerosols using a single optical property may introduce substantial biases in model outputs.*

Old version: “This choice of species includes both absorbing and scattering OA and enables more accurate representation of OA in climate models and satellite retrievals, improving aerosol radiative forcing estimates.”

New version: “This choice of species that includes both absorbing and scattering OA along with their mass fraction and size distribution measurements from the field will allow more accurate modeling of biomass burning smoke and urban optical parameter computations in climate models and satellite retrievals, improving aerosol radiative forcing estimates.”

7. Although the proposed classification is based on IRI, the corresponding MAC and SSA thresholds are ultimately derived from prescribed particle size distributions. Given that aerosol absorption, SSA, and radiative forcing are all highly sensitive to particle size characteristics, particle size distribution may represent a source of variability comparable to refractive index itself (<https://doi.org/10.5194/acp-26-3107-2026>, <https://doi.org/10.1029/2025GL117418>). Consequently, the robustness and transferability of the derived MAC- and SSA-based thresholds across different aerosol size regimes and atmospheric conditions remain unclear and warrant further discussion.

Response: *We thank the reviewer for this insightful comment and for pointing us to these interesting articles. We agree that the aerosol size distribution can play an important role in determining the classification thresholds for SSA and MAC values. In our computations, we have used field-measured size distributions for the different aerosol species. However, we acknowledge that variations in the size distribution can lead to different threshold values for MAC and SSA. Therefore, we plan to include computations based on different field-measured size distributions corresponding to specific regions, sources, and/or altitudes in the TAO database. To clarify this point, we have added the following paragraph to the caveats and limitations section of the manuscript.*

Old version: In addition, computation of MAC and SSA values using Mie theory relies on several simplifying assumptions. These include the treatment of aerosols as homogeneous and spherical with externally mixed compositions and size distributions. Real atmospheric aerosols may deviate from these assumptions due to internal mixing, non-sphericity, and morphological complexity.

New version: In addition, computation of MAC and SSA values using Mie theory relies on several simplifying assumptions. These include the treatment of aerosols as homogeneous and spherical with externally mixed compositions and size distributions. In this manuscript, we provide threshold values based on a single set of field-measured size distributions for each OA species. However, aerosol size distributions can vary substantially depending on the source, region, altitude, and atmospheric conditions, which may consequently lead to variations in the corresponding MAC and SSA threshold values. To account for this variability, we plan to include computations based on region, source, and/or altitude specific field-measured size distributions in the TAO database.

8. Table 5 appears to contain a typographical error: the SSA range for W-BrC at 300 nm is listed as “0.87-92”, which should likely be “0.87-0.92”.

Response: *We thank the reviewer for catching this typo. We will fix that in table 5.*

Old version: 0.87 – 92

New version: 0.87 – 0.92

9. The statement that the proposed framework will improve climate-model and satellite-retrieval estimates should be softened unless additional quantitative evidence is provided.

Response: *We thank the reviewers for this comment. We computed direct radiative forcing using Santa Barbara DISORT Atmospheric Radiative Transfer (SBDART) code for OPAC-style OA, single non-absorbing OA, and a mixture of organics that represent smoke. The following section will be added to the manuscript.*

“To demonstrate the importance of organic aerosol (OA) classification in determining its radiative effect, we provide a case study the Santa Barbara DISORT Atmospheric Radiative Transfer (SBDART) model to calculate the net radiative flux at the top of the atmosphere (TOA). SBDART requires aerosol optical properties, including the single-scattering albedo (SSA), asymmetry parameter, and extinction efficiency, together with atmospheric and surface parameters such as solar zenith angle, season, and surface albedo. The difference in TOA net radiative fluxes between aerosol-loaded and aerosol-free conditions was used to calculate the TOA direct radiative forcing (RF) associated with the aerosol layer.

TOA RF was calculated for four aerosol cases: (1) OPAC water-soluble OA, (2) OPAC water-insoluble OA, (3) biogenic OA represented as a non-absorbing aerosol, and (4) a mixture of organic and carbonaceous aerosol components representative of smoke. The smoke mixture was constructed based on the mass fractions of individual OA components reported by Posfai et al. (2003) for smoldering young smoke from Kruger National Park during the SAFARI 2000 field campaign. The mixture consisted of relative number concentrations of 17% black carbon (BC), 17% tarballs, and 66% scattering OA.

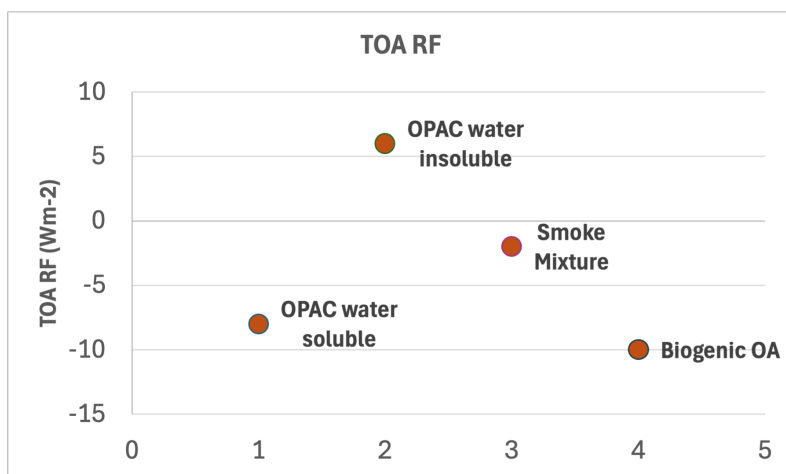


Figure: Top of the atmosphere radiative forcing calculations for a layer of aerosols in the atmosphere. The plot shows the radiative forcing for a single layer of : 1) OPAC water soluble, 2) OPAC water-insoluble, 3) Biogenic OA, and 4) Smoke Mixture. The calculated TOA RF was -8 W m^{-2} for the OPAC water-soluble aerosol, $+6 \text{ W m}^{-2}$ for the OPAC water-insoluble aerosol, and -10 W m^{-2} for the non-absorbing biogenic OA. In contrast, the mixed smoke aerosol produced a TOA RF of -2 W m^{-2} . These results demonstrate that the assumed chemical composition and corresponding optical properties of OA can substantially influence the estimated radiative effect. Representing smoke using a single OA component may substantially overestimate or underestimate its net radiative forcing, depending on the assumed optical properties. Explicitly accounting for the contributions of scattering OA, tarballs, and BC therefore provides a more realistic representation of the radiative effects of smoke aerosol in climate models and radiative forcing calculations.

10. The manuscript should add a short discussion comparing the proposed multi-wavelength IRI classification with previous approaches based on k_{550} , AAE, MAC, or SSA.

Response: We thank the reviewers for this suggestion. We have added the following plot along with the discussion to the manuscript:

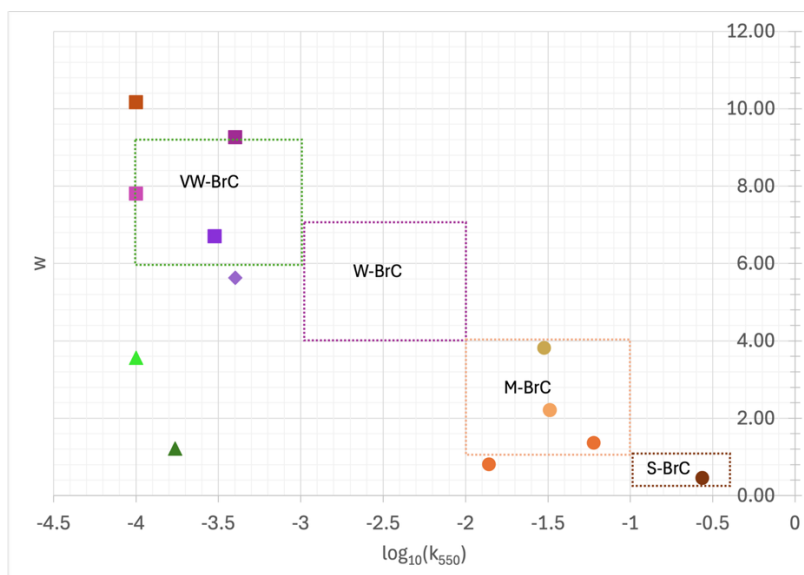


Figure: Comparison of aerosol species classification obtained in this study with the classification proposed by Saleh et al. 2020. The dotted boxes show the thresholds proposed by Saleh et al. 2020 for VW-BrC, W-BrC, M-BrC, and S-BrC. The classification in this study is represented using markers as: triangle (VW-BrC), square and diamond (W-BrC), and circles (M-BrC and S-BrC) as in the previous plots.

We calculated the wavelength dependence (w) following the approach described by Saleh et al. (2020), using the IRI values of each species at 550 and 350 nm, and compared the resulting k_{550} – w distributions with the classification thresholds proposed by Saleh et al. (2020). As shown in the figure, the IRI classes identified in this study occupy regions of the k_{550} – w space that differ from those defined by Saleh et al. (2020). One possible explanation for this discrepancy is the difference in the optical parameters and methodologies used to derive w . In Saleh et al. (2020), w was derived using MAC, IRI, and AAE values reported in the literature, and the reported MAC and AAE values were converted to k_{550} and w using the small-particle approximation. In contrast, the present study derives w directly from the IRI values at 350 and 550 nm. Despite these differences, some species in the present study are consistent with the classification thresholds proposed by Saleh et al. (2020). For example, SOA generated from aromatic VOCs (square markers) falls within the VW-BrC threshold, while less-volatile BrC species, such as tar balls, fall within the M-BrC and S-BrC threshold ranges.