Updated aerosol optical properties for the Goddard Earth Observing System (GEOS) Earth system model

Osku Kemppinen[1], Peter Colarco[1], Reed Espinosa[1], and Patricia Castellanos[1]

[1]NASA Goddard Space Flight Center

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Abstract

The Goddard Earth Observing System (GEOS) global atmospheric model tracks and transports several individual aerosol species. A key contribution by these aerosols is to interact with solar radiation. When calculating the aerosol-radiation interactions, pre-computed look-up tables of aerosol optical properties are used.We have recently finished an effort to update the aerosol optical properties used in the GEOS model. This has been accomplished with a full rewrite of the optical property simulation code into a Python-based version. In addition to structural changes to the code (outlined below), there are some concrete changes to the aerosol particle definitions. First, truncated lognormal size distributions have been replaced with non-truncated ones, and sub-bin size resolutions of all simulations have been enhanced. Additionally, non-spherical dust accuracy has been improved due to switching to a different spheroidal kernel database. Finally, dust size distribution has been changed from a continuous power law distribution to a bin-specific lognormal distributions.There are also significant changes in the convenience and flexibility of adding or modifying aerosol types for future work and other investigations. Particle properties are now defined exclusively in resource files rather than in the code. This allows for easy addition or modification of aerosol particles, with no need to touch the code. Relatedly, the code can be run either with a provided command-line interface, or via a custom script or notebook. That is, no Python knowledge is needed to generate aerosol particle optics, making the tool easy to use. Additionally, particle types are fully decoupled from specific size distributions, hydration schemes, and other type-specific properties. This also means changing, e.g., a particle size distribution type for a given particle is simple. Performance is significantly improved due to novel Mie simulation optimizations. This enables the aforementioned high size resolutions to be used without concerns for processing time.

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Osku Kemppinen[1,2] (osku.kemppinen@nasa.gov),Peter Colarco[1], Reed Espinosa[1], Patricia Castellanos[1]

[1]NASA Goddard Space Flight Center, Greenbelt, MD, USA
[2]Earth System Science Interdisciplinary Center, University of Maryland, College Park, MD, USA

Background

- The GEOS-5 model uses aerosol optical properties for both radiative forcing calculations as well as calculating diagnostic AOD values for observation comparisons
- We have recently finished an effort to update the aerosol optical properties used in the GEOS model
- This has been accomplished with a full rewrite of the optical property simulation code into a Python-based version
- In addition to structural changes to the code (outlined below), there are some concrete changes to the aerosol particle definitions
- First, truncated lognormal size distributions have been replaced with non-truncated ones, and sub-bin size resolutions of all simulations have been enhanced
- Additionally, non-spherical dust data quality has been improved due to a switch to a different spheroidal kernel database

Design of the new software package

- The objective was largely to replicate the resulting optical properties with the new system but with an updated software structure
- The new system is implemented in the open source language Python, rather than proprietary IDL
- Whereas the previous package implemented each aerosol particle with a separate program that contained plenty of redundant code, the new system utilizes one central program that simply reads in aerosol particle definitions from a data file
- Data-driven design also means modifying or adding particles requires no modifications to any of the code files
- A flexible kernel system has been added do allow the usage of not just spheroids but any suitable pre-calculated shape database
- Any updates, such as adding a new particle size distribution type, are also available to every aerosol type without having to be implemented or copied separately

Structure of the software package

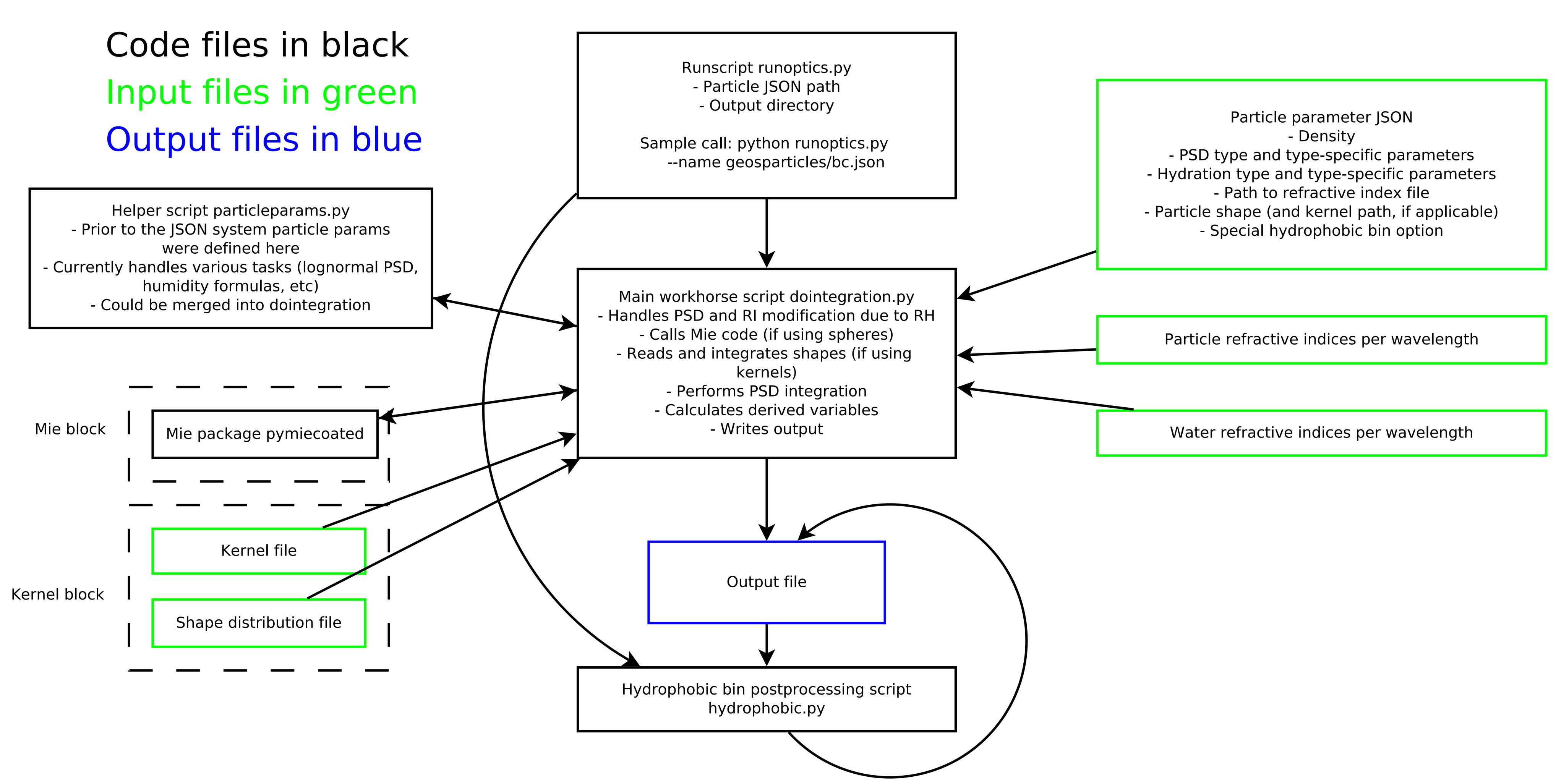

Figure 1: Schematic of the software package structure.

Performance improvements

- Code performance is significantly improved due to novel Mie simulation optimizations
  - The Mie package is based on high performance (compiled) Python code, modified from pymiecoated package by Jussi Leinonen
  - Additionally, the code pre-calculates several internal Mie parameters such as the angular eigenfunctions, which saves up to 50% computational time in each simulation
- Improved performance allows one to use significantly higher resolution for size distributions, which improves the reliability of the results (see Fig. 3)

Metrics of the new system compared to the legacy system.

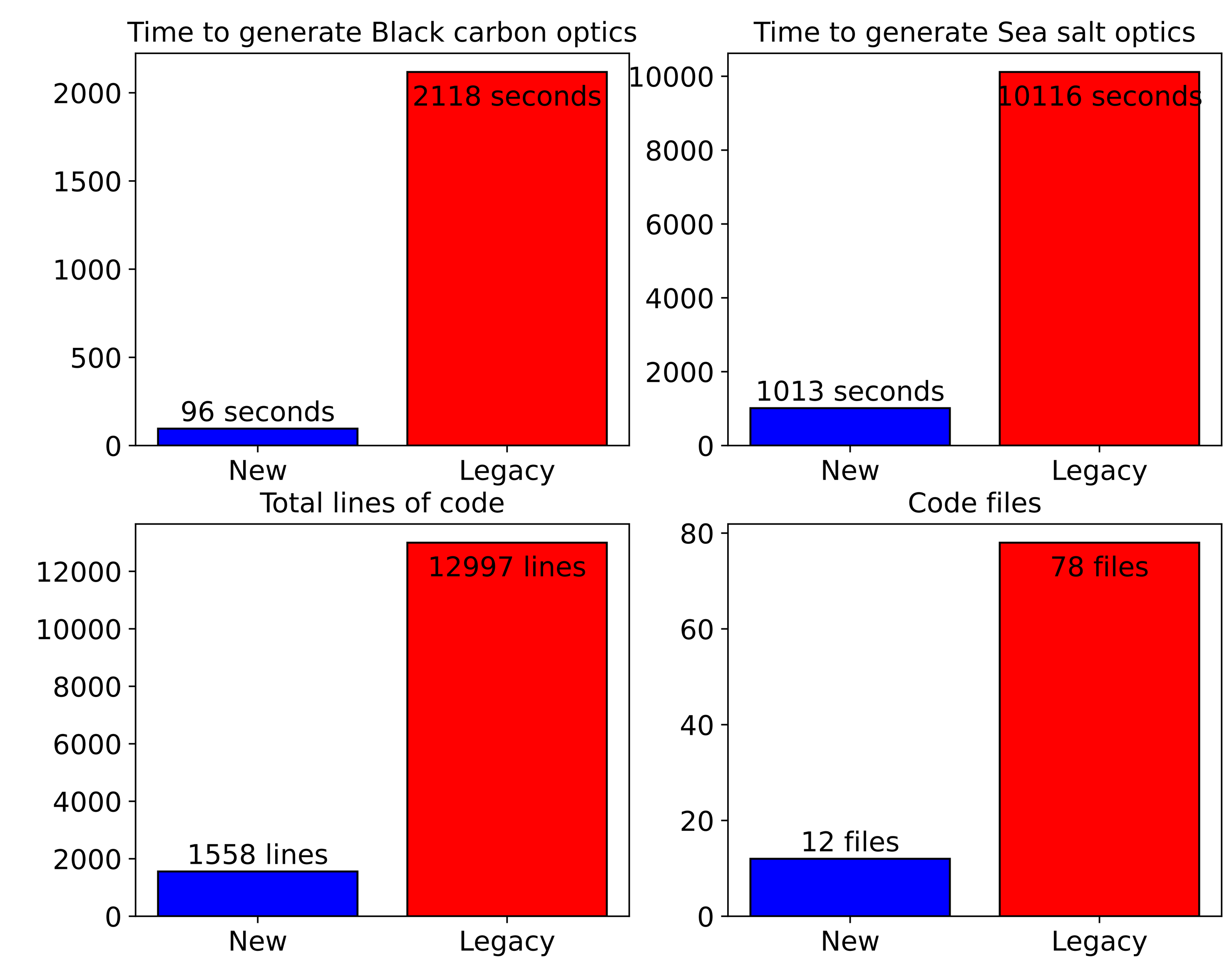

Figure 2: Organizational and performance metrics of the new system compared against the legacy system. Significant performance improvements have been achieved due to the new Mie backend that has been optimized for repeated simulations. Vastly improved performance allows simulations to be performed at higher size resolutions, which can prevent unphysical behavior (see Fig. 3). In addition to the performance improvements, the modular design simplifies the codebase significantly in terms of both the number of files and the number of total code lines.

Effect of size resolution on simulation results

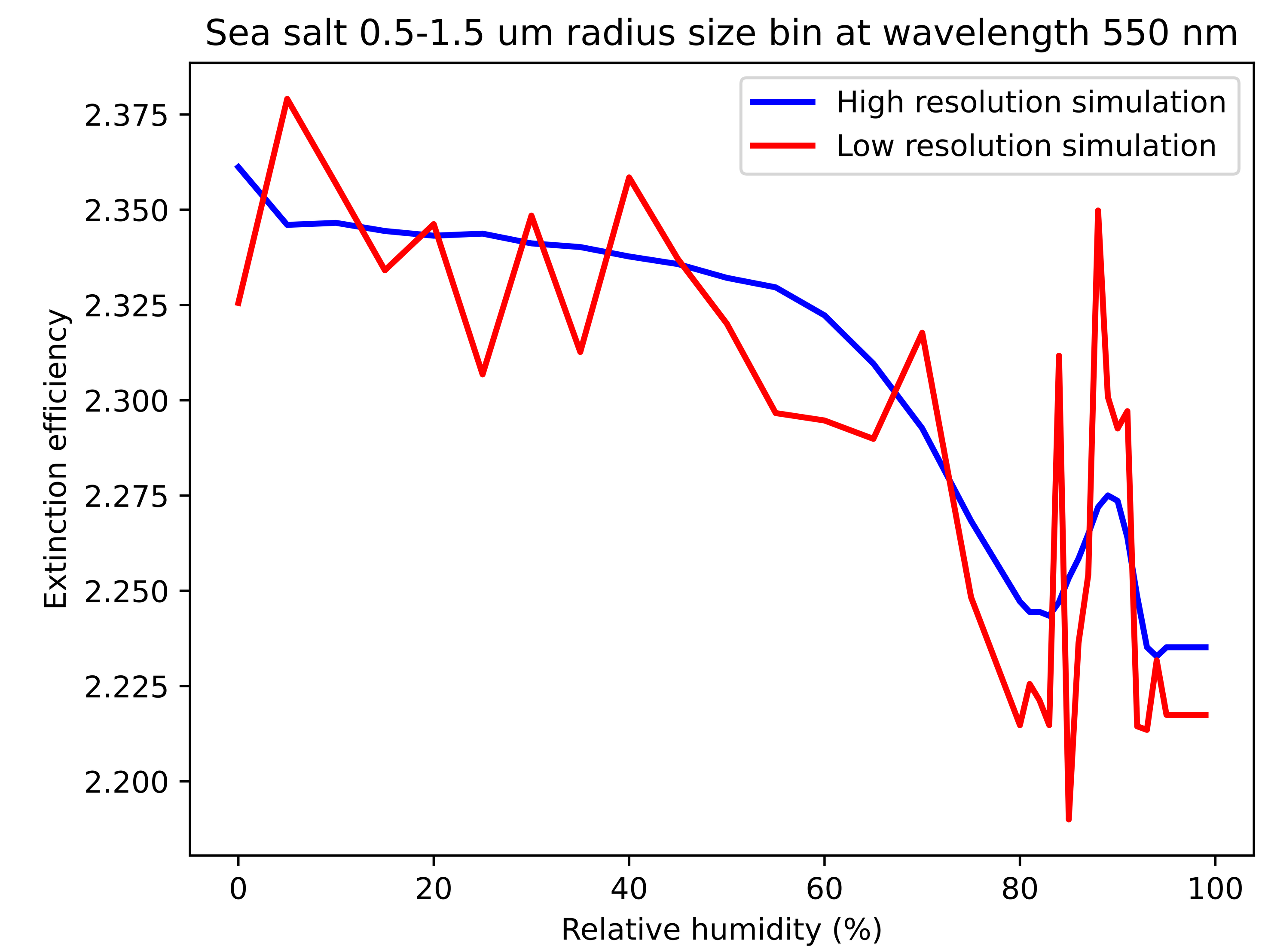

Figure 3: Effect of insufficient size resolution on simulated sea salt extinction efficiency. Sharp variations as a function of the relative humidity are unphysical and can cause errors of a few percent.

Summary

- **A new Python-based, easy-to-use optical table calculation tool has been created**
- **As designed, it replicates the results of the legacy tool to within a rounding error, except when the legacy tool used e.g. insufficient size resolution**
- **Data-driven design makes adding or modifying aerosol types easy**
- **Computational performance is 10-20x better than in the legacy system**

Future plans

- **The new package will be made public via the GEOS Git repository (https://github.com/GEOS-ESM/) in the future**
- **The new package enables new types of studies with GEOS, such as:**
  - **Using a large variety of dust compositions**
  - **Using a modal aerosol scheme**
  - **Using core-shell aerosol types**
  - **Using novel kernels, such as the new Saito et al. dust database**

Correspondence to: osku.kemppinen@nasa.gov