Simulation of the aerosol size distribution using a neural network surrogate for the Modal Aerosol Module (MAM7)

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Abstract
One objective of atmospheric simulations is to quantify the distribution of aerosols and their properties. Accurate parameterizations of the processes governing aerosol mass, particle number, and particle size distribution are important for predicting the Earth’s net radiative balance and aerosol-cloud interactions. The Modal Aerosol Module (MAM7) is a two-moment aerosol model that simulates mass, number, and size distribution of seven modes comprised of internally mixed aerosol species. The two-moment scheme adds significant computational expense but allows for the prediction of varying particle size distribution relative to the bulk method which predicts only total mass. In this work, we developed a neural network surrogate model for MAM7 (MAMnet) to predict the aerosol number concentration in NASA’s Global Earth Observing System (GEOS) without adding prohibitive computational expense. MAMnet, can be driven by output from a single moment, mass-based, aerosol scheme (Goddard Chemistry Aerosol and Radiation model (GOCART)) or from reanalysis products (Modern-Era Retrospective analysis for Research and Applications, Version 2 (MERRA-2)). MAMnet was trained using number concentrations from a 5-year GEOS/MAM7 simulation at 1-degree horizontal resolution and using the total mass calculated across modes as inputs, as well as temperature and air density. The model architecture for MAMnet was based on AlexNet, the 2012 winner of the ImageNet Large Scale Visual Recognition Challenge. While some modifications were necessary to accommodate our problem, important aspects of the network were preserved. MAMnet was able to reproduce zonal dynamics and spatial distributions of the aerosol number concentration however predictability in the upper troposphere was poor.

How are aerosols represented in GEOS?

The Global Earth Observing System (GEOS) model includes a suite of components that numerically represent different aspects of the Earth system. The Modal Aerosol Module (MAM7) was developed to simulate aerosol size distribution and number concentration, but neglects spatiotemporal predictability in the upper troposphere. After testing MAMnet on reserved aerosol test data, MAMnet was applied to GOCART inputs. GOCART is the operational aerosol module in GEOS but neglects spatiotemporal predictability in the aerosol size distribution (see Table 1). Figure 3 shows a comparison between the GEOS-MAM test set (left) and the MAMnet(GOCART) prediction (middle). As a final test, we applied MAMnet to MERRA-2 reanalysis data, which are used to drive GEOS, and compared the output with observational data (Figure 4). In some cases, correlation was high (>0.6), but further improvements are necessary. We are currently working with an additional probabilistic framework to assimilate observations during training.

These tests indicate that inputs from a low fidelity model (GOCART) can be successfully replicated by a 3-degree high fidelity model (MAM7) using a surrogate neural network (Fig. 3).

Lastly, while MAMnet is able to reproduce observational data with some degree of accuracy, more development is necessary (Fig. 4).

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Results and Summary

Did the MAMnet accurately learn the physical problem?

YES

Overall, MAMnet was able to reproduce the test data (not used during training/validation), indicating that MAMnet was trained on a dataset that encapsulated the statistical variability of the system and “learned” patterns from data as opposed to overfitting. Additionally, this test suggests that the AlexNet architecture was successfully adapted for a regression task on atmospheric data.

Is the model useful – can it be applied to new data?

YES

After testing MAMnet on reserved aerosol data (MERRA-2), one could compare with near-surface observational datasets (blue). See Asmi et al. (2011) for site descriptions.