Development and Evaluation of Coupled Climate Simulations Using Machine Learning-Enhanced Aerosol Model

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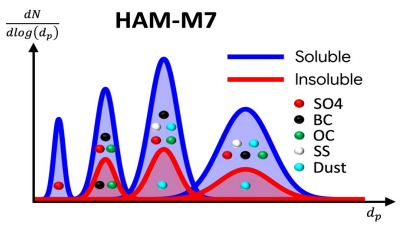
1. Background
Global-Scale Aerosol Modelling

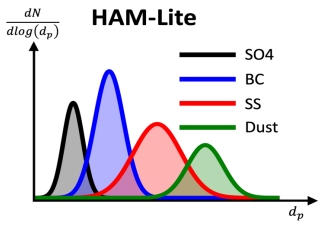
- TerraDT aims to advance Earth's digital twins as part of the Destination Earth initiative.
- Microscopic aerosol processes are complex and computationally demanding to model over large areas, but essential for representing their kilometer-scale impacts on cloud systems.
- Current aerosol models are either computationally too heavy or too simplified and inaccurate for global scale modelling.



1. Complex Aerosol Model HAM-M7

- Simulates aerosols as 7 log-normal modes and total of 25 tracers.
- Tracers can be soluble or insoluble and are divided into different size classes.

The model is computationally too heavy for global scale modelling.



2. Simple Aerosol Model HAM-Lite

- Simplified version of HAM-M7. Simulates aerosols as 4 tracers, each in one soluble log-normal mode.
- The model includes emissions and sinks, but not any microphysics between them.
- Computationally efficient for global scale modelling.

The model is too inaccurate.

2. Problem
Too Simplified Model

- HAM-Lite is made for global scale modelling but it is too simplified and inaccurate to make good predictions. **It has preset, constant hygroscopicity for each tracer and very simplified calculation for extinction coefficient.**
- With more detailed processes the model would become computationally too heavy. It needs to be made more accurate without increasing the computational cost significantly.

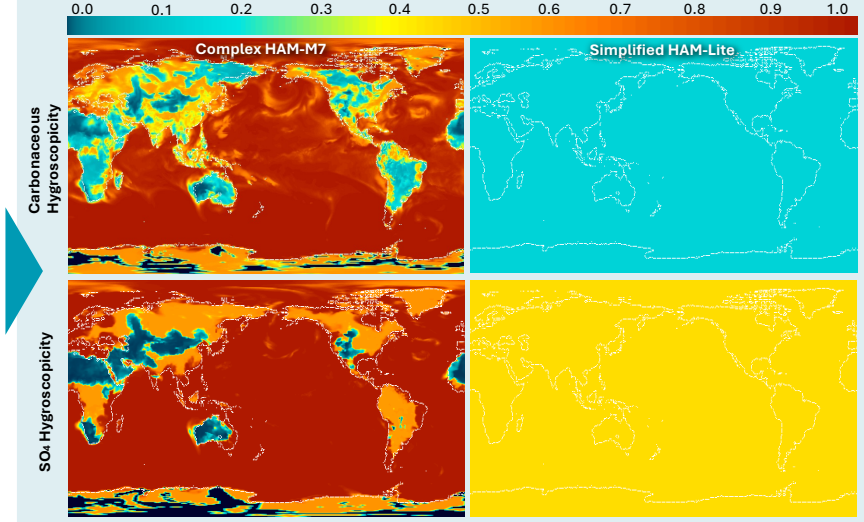


Figure: Carbonaceous and SO_4 hygroscopicity from HAM-M7 (left) and HAM-Lite (right).

3. Solution
Boosting with Machine Learning

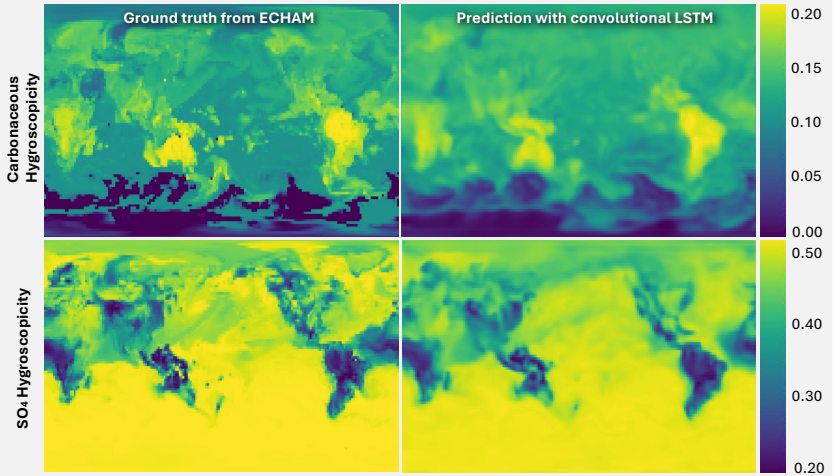
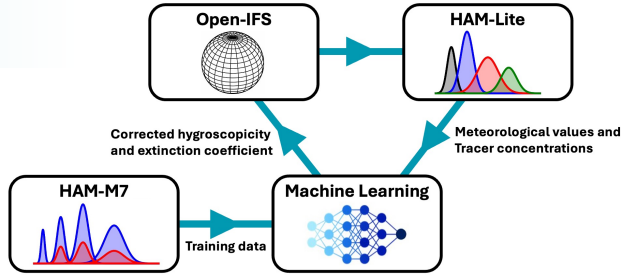


Figure: First predictions of hygroscopicity at surface level using Convolutional LSTM and training data from ECHAM. Carbonaceous hygroscopicity (top) and SO_4 hygroscopicity (bottom) from ECHAM and corresponding predictions.

- **Machine learning component is implemented for HAM-Lite to predict hygroscopicity κ and extinction coefficient α_{ext}.**
- The training data is obtained from the complex HAM-M7 aerosol model coupled with a global climate model Open-IFS. Meteorological values and tracer concentrations from surrounding grid points in space and time are used as input data.

4. Goal
Coupled System

- **Goal is to have a lightweight and accurate aerosol model with a machine learning component correcting hygroscopicity and extinction coefficient at runtime.**
- Simulations will be implemented and evaluated with a global kilometer-scale climate model Open-IFS and later with Integrated Forecasting System (IFS), coupled with the new boosted aerosol model.
- IFS coupled with boosted HAM-Lite will be the atmospheric component of TerraDT digital twins.



5. Take-Home Message

- Current aerosol models are either too simplified or computationally too heavy for global scale climate modelling.
- In this study we enhance a simple and lightweight aerosol model HAM-Lite with machine learning methods. Training data is obtained from a more accurate and computationally heavy aerosol model HAM-M7.
- The new aerosol model learns to predict results of a more complex model with less computational cost. This model will be coupled with a global climate model.

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