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EAM QuickView: A simulation data visualizer for the E3SM Atmosphere Model

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Summary

EAM QuickView is a visualization application (app) providing overviews of the geographical distribution of quantities simulated by a global atmospheric model, the Energy Exascale Earth System Model (E3SM) Atmosphere Model (EAM), directly from the NetCDF files generated by simulations. Compared to existing visualizers, EAM QuickView supports displaying multiple quantities and arranging different figures by drag-and-drop, as well as saving the state of the visualization and resuming at a later time. Under the hood, the app uses the Python-based trame framework to create a simple and tailored user interface (UI) to the general-purpose data analysis and visualization tool ParaView. This design makes ParaView easily accessible to atmospheric scientists without requiring expertise in visual analytics.

Statement of need

EAM, like many other simulation codes used in Earth system sciences, solves a complex set of equations and writes out results for a large number of physical quantities in the form of NetCDF files. After a simulation is completed and before more detailed analyses are performed, it is often useful to obtain a first impression of the characteristic values of the simulated quantities and their geographical distributions. The atmosphere modelers' wish for tools that can simultaneously present multiple variables has become more prominent in recent years due to the rapid increase of model complexity in terms of the number of equations solved by the numerical models and the number of variables typically archived in the NetCDF files. For example, to inspect the simulated aerosol life cycles, it is very useful to examine the concentrations of multiple chemical components in different particle size ranges (see Figure 1).

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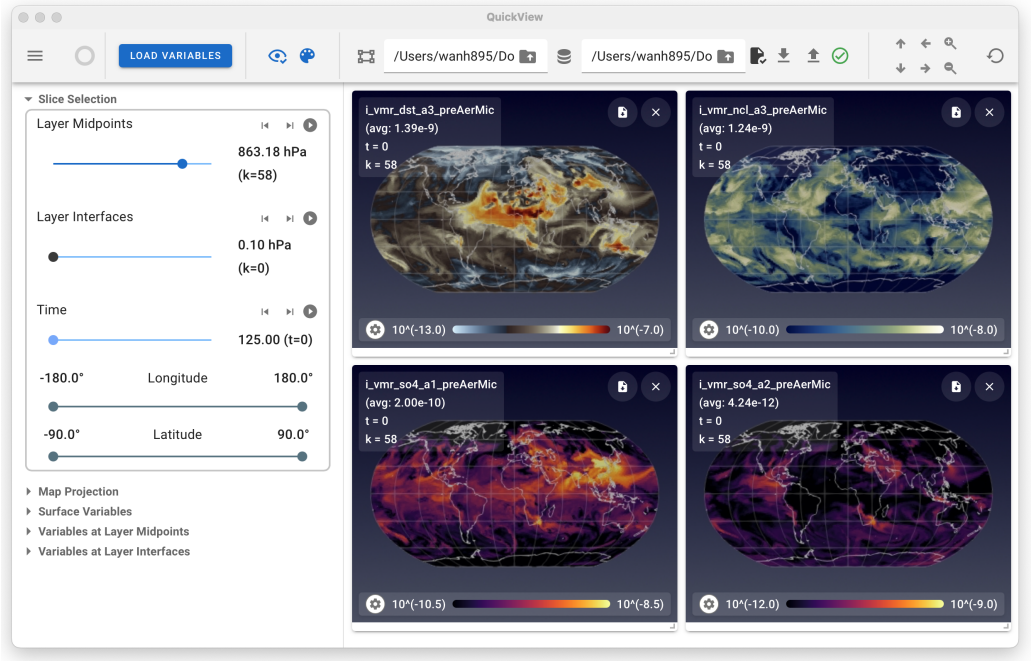

Figure 1: Figure 1: Aerosol concentrations simulated by EAMv2.

State of the field

Several tools exist for quick visualization of NetCDF files produced by Earth system models. ncview (Pierce, 1993) has been widely used in Earth system modeling communities for rapid, push-button inspections of NetCDF files. The newer tool ncvis developed by (Ullrich, 2022) and inspired by ncview extends this capability to data defined on unstructured meshes, making it usable out of the box for a broad range of models and mesh types. While EAM QuickView is also designed for rapid inspections, it was developed to address the need to simultaneously display multiple variables in a single viewport and to support flexible rearrangement of variables during scientific reasoning. To facilitate this more sophisticated analysis workflow, QuickView also includes session persistence via state files that can be saved and reloaded, allowing users to resume analysis and achieve provenance.

To leverage state-of-the-art capabilities in visual analytics, EAM QuickView uses ParaView (Ahrens et al., 2005; Henderson, 2007) as its visualization engine, thereby inheriting ParaView's extensive collection of analysis algorithms and its built-in support for parallel processing of large data sets—capabilities that are indispensable for atmospheric models in the era of high-resolution modeling. By design, EAM QuickView departs from ParaView's general-purpose UI which presents a steep learning curve and has repeatedly proven to be a barrier to effective use for scientists unfamiliar with the visual analytics paradigm. Instead, EAM QuickView provides a UI explicitly tailored to the scientific language and reasoning workflows of atmospheric modeling. The UI is intentionally focused on rapid inspection of simulation output. In this sense, EAM QuickView represents the first prototype in a family of ParaView-based analysis UIs that is purpose-built for atmospheric applications. Additional members of this tool family currently under development target workflows such as rapid comparison of multiple simulations and flexible slicing of three-dimensional fields using arbitrary planes and bounding boxes.

Software design

EAM QuickView is built on the trame framework (Kitware Inc., 2024a) and is distributed as a native desktop application using Tauri (Tauri Foundation, 2024) via the trame-tauri library (Kitware Inc., 2022). Trame enables developers to control application behavior through triggers and change listeners on UI elements while providing widgets that integrate with visualization tools including ParaView. The trame-vtk widget (Kitware Inc., 2024b) is used specifically for displaying ParaView renderings within the Trame application, providing seamless integration of VTK/ParaView visualization capabilities. ParaView's Python plugin system allows developers to create readers, filters, and writers entirely in Python without recompiling the C++ application, significantly accelerating development. For QuickView, custom NetCDF readers and specialized filters for processing EAM data were implemented as Python plugins. Tauri transforms the web application into a native desktop application, eliminating the need for users to install ParaView or configure Python environments by bundling all dependencies into a single executable with smaller application sizes and lower memory usage compared to alternatives.

Since the initial work was focused on facilitating the development of EAM, our app is designed to work with the cubed sphere horizontal mesh and the pressure-based terrain-following vertical coordinate. The adaptation of EAM QuickView for other models and meshes can be done by updating the ParaView Reader in the app.

Research impact statement

Early adoption of EAM QuickView before its version 1 release has demonstrated the utility of the multi-panel visualization and session persistence features for iterative model development and debugging workflows. The release of EAM QuickView version 1 has triggered interests from the developers of other (e.g., land, ocean, and ice) components of the E3SM model. Work has started to generalize the app to support the meshes and file formats of these other model components.

AI usage disclosure

No generative AI tools were used in the development of this software. Some of the paragraphs in this manuscript were edited by ChatGPT to improve grammar and readability; the text edited by ChatGPT was reviewed and further revised by the authors to ensure the adopted edits conveyed the intended messages.

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