

Visualizing the Impact of the Asian Summer Monsoon on the Composition of the Upper Troposphere and Lower Stratosphere

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ABSTRACT

This paper presents an explanatory-track visualization which utilizes multiple open-source graphics tools, including the C++ library OpenVDB and the 3D animation software Blender, to create a cinematic representation of simulation data generated in support of the Asian Summer Monsoon Chemical and Climate Impact Project (ACCLIP) campaign. After a brief summary of the project and data simulation, the process and techniques used to create the visualization are explained in detail.

1 Science

The Asian summer monsoon (ASM) has long been known for its generation of seasonal rainfall over portions of eastern and southern Asia. A recent line of research has focused on the air mass that is transported from the Asian boundary layer into the upper troposphere and lower stratosphere (UTLS) by ASM deep convection. Water vapor and tropospheric pollutants transported in this way have the potential to impact global atmospheric composition and climate (e.g., Dethof et al., 1999; Fu et al., 2006). The application of chemical and transport modeling techniques to predict the ASM's impacts on global atmospheric composition remains an active research area (e.g., Smith et al., 2023; Clemens et al., 2023). To investigate the impacts of ASM transport on UTLS composition, the Asian summer monsoon Chemical and Climate Impact Project (ACCLIP; <https://www2.acom.ucar.edu/acclip>) was planned to sample the ASM UTLS air mass using two research aircraft outfit with chemistry and aerosol instrumentation (Pan et al., 2022). The ACCLIP field phase took place in summer 2022 and sampled the UTLS over the western Pacific.

As a part of ACCLIP operations, global atmospheric models including chemistry were initialized for use by the forecasting and flight planning teams. One such simulation was performed using the Multi-scale Infrastructure for Chemistry and Aerosols (MUSICA; Schwantes et al., 2022), which has the capability for user-customized grid refinement to improve sampling over a specific region of interest. For the ASM application, the grid is refined from ~100 km global grid spacing to ~30 km grid spacing

over Asia and parts of the western north Pacific (shown in Figure 1). The simulation was performed on the NCAR Cheyenne supercomputer over July – September 2022, with output provided at 3-hour intervals. The simulation required ~1800 processors, or 50 compute nodes on Cheyenne, to run. A tropospheric chemical tracer (carbon monoxide, CO) field output from the MUSICA simulation was visualized as described in the following sections to highlight the importance of ASM convection in redistributing boundary layer air masses into the UTLS. ACCLIP airborne observations provide a unique opportunity to evaluate the representation of the ASM mechanism by global chemistry models, paving the way for improved predictions of its impacts on the Earth system and its climate.

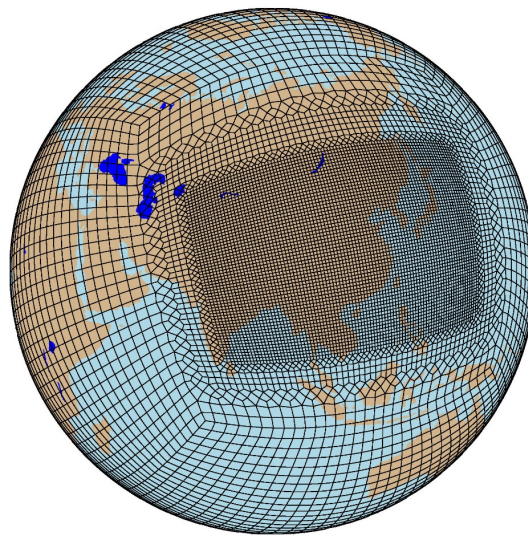


Figure 1: The MUSICA grid structure used by the simulation shown in the animation. The grid refinement ranges from ~100 km globally to ~30 km over most of Asia and parts of the western north Pacific.

2 Visualization Methods

2.1 Software

Blender was selected as the primary visualization tool because it is free yet highly supported software and has been used in many previous visualization projects. It allows finite control of camera movement, lighting, object properties, and many other attributes. Additionally, Blender has recently been updated with some powerful libraries, including OpenVDB for reading and animating volumetric data and NVIDIA OptiX for GPU rendering and denoising.

OpenVDB is a vast library used in movies and video games to produce realistic cloud images and volumetric effects. The files are built on a tree structure, and functions in the library can heavily reduce file size by skipping sparse values in the volume. (<https://www.openvdb.org/documentation/doxygen/overview.html>) Converting the NetCDF time step files produced by the simulation to OpenVDB files reduced the data per time step from around 120MB to 5MB each. The time steps could then be quickly loaded at each frame of the animation in Blender.

2.2 Data Processing

OpenVDB objects in Blender exist as voxels positioned on a rectilinear grid, so the data on the variable grid of the MUSICA model needed to be interpolated. Delaunay triangulation from the SciPy Spatial library (<https://docs.scipy.org/doc/scipy/reference/generated/scipy.spatial.Delaunay.html>) was used to find the triangles based on the latitude and longitude coordinates from MUSICA, and Linear ND Interpolator from the SciPy Interpolate library (<https://docs.scipy.org/doc/scipy/reference/generated/scipy.interpolate.LinearNDInterpolator.html>) was run on each plane to fit the data to the rectilinear grid in XY Cartesian coordinates. The Z dimension was determined by converting the atmospheric pressure value to kilometers.

The data variable selected from the simulation was carbon monoxide concentration, as it is a good tracer of the polluted air masses intended to be sampled in the real-world study. The CO concentration was mapped to the OpenVDB fields of density and color. The lowest concentrations, including those below a certain background threshold, are completely transparent. The values of interest increase linearly from dark blue and more transparent to cream colored and opaque.

2.3 Animation

Earth was represented by a mesh object with a displacement modifier, deformed by the topography map from the NASA Visible Earth website. (<https://visibleearth.nasa.gov/collection/1484/blue-marble>). The elevation is highly exaggerated compared to the land in order to make the data distinguishable and to clarify convection events spanning the different layers of atmosphere. The height of the terrain was not increased to scale, as it would be approaching 9

km in the tallest mountains, and this would obstruct the data in some camera angles.

The camera was animated with various keyframes to highlight the transition from the overhead view to the three-quarter view, and to increase the viewer's perception of the depth of the volumetric data. The camera's view and rendering size was set at 3840 x 1920 to be near ultra-high definition (normally 3840 by 2160 pixels), while maintaining a 2:1 ratio. This wide-screen ratio fit more of the earth object in the frame and emphasized the east-west direction of the CO fluid motion.

2.4 Rendering and Post-Processing

The frames were rendered at the sizes previously mentioned using NVIDIA OptiX, which is available as part of Blender's Cycles rendering engine.

(https://docs.blender.org/manual/en/latest/render/cycles/gpu_rendering.html) OptiX denoiser was used to reduce the number of samples required to eliminate noise, especially in the volumes.

The animation frames and other components of the video, including the voiceover audio track, were composited in Adobe Premiere and exported for the final version.

3 Conclusion

This visualization highlights the important work from the ACCLIP mission and has served to promote awareness of the campaign. It is also an example of the potential that OpenVDB has for the visualization of large volumetric data sets. Rendering each frame took a reasonable, but not insignificant, amount of time (around 1 minute) on a single NVIDIA Quadro RTX 5000 GPU. However, the loading of the OpenVDB files at each timestep was negligible compared to the actual render time. This is a significant improvement with regards to visualizing volumetric data and evidence for the library's usefulness as a visualization tool.

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