DYAMOND++ A high resolution Climate Model Setup

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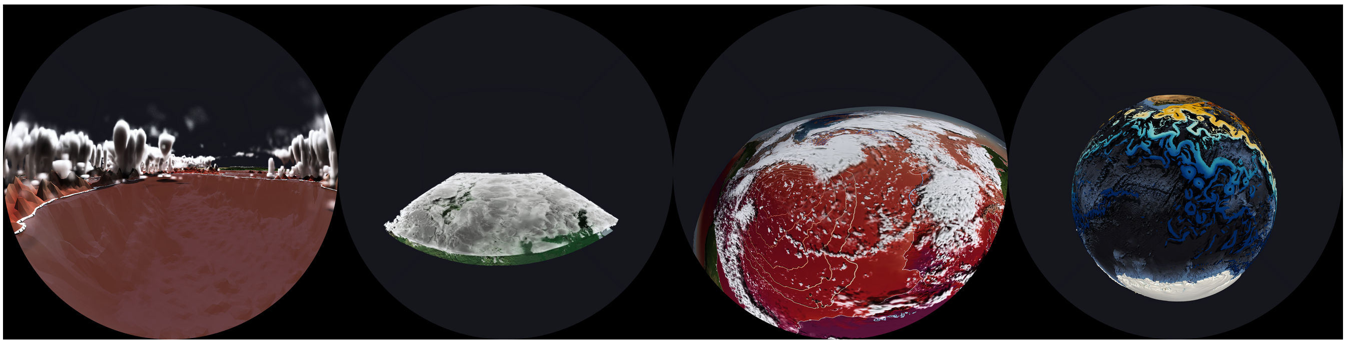

Figure 1: *Scenes from the Film: DYAMOND++ A high resolution Climate Model Setup*

Abstract

Climate simulations clearly belong to the most data intensive scientific disciplines. The output generated by current models is increasing in size, as well as complexity. The increase in complexity is due to a maturing of models that are able to better describe the intricacies of the climate system, while the gain in size is a direct result of finer spatial and temporal resolutions that are required to capture those small scale processes.

DYAMOND++ is a project using the globally coupled Earth system model ICON-ESM that permits global simulations at a resolution of 5km to study a wide range of Earth's weather and climate phenomena. The visualization of these large data sets is not trivial, and large, high resolution display surfaces, such as 4k screens and planetarium domes, are very suitable to convey the complex information within.

This short film describes the development of DYAMOND++, from low resolution climate models in the past, to high resolution regional setups to study clouds and cloud building processes in greater detail. We interviewed some of the scientific minds behind the DYAMOND++ project, and show visualization examples of their work. The visualizations are produced using ParaView and Intel's OSPRay raytracing engine.

CCS Concepts

• ***Applied computing*** → *Media arts;* ***Environmental sciences;*** • ***Human-centered computing*** → ***Scientific visualization;***

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1. Introduction

ICON, the **ICO**sahedral **N**on-hydrostatic model, that is jointly developed by the Max Planck Institute for Meteorology (MPI-M) and the German Weather Service (DWD), is a framework based on an icosahedral grid with an equal area projection, on which data sets are sampled via primal triangular cells, dual hexagonal cells and hybrid quadrilateral cells. The vertical layout is a rectilinear grid, that is sampled more densely in close proximity to the Earth's and Ocean's surface. ICON – though unstructured – has several advantages, as it has no computational poles, allows an easy refinement in local areas and provides a simplified coupling between its oceanic, atmospheric and land components. Over the last years, ICON was extended to permit large eddy simulations at cloud resolving resolutions in a regional setup as part of the HD(CP)^2 project [HDH*16; SAH*20] to advance the understanding of clouds, cloud building and precipitation processes. Although the data produced was quite large (22 million cells per 2D level and 3.5 billion cells in 3D), a classic post visualization approach using ParaView employing a parallel processing/visualization setup on several fat nodes was still possible. For simulations that are planned within the recently started EU project ESiWACE – aiming at a 1km global resolution – other visualization workflows, such as in-situ visualization and a wavelet-based data decomposition and progressive rendering, are currently examined and implemented [SSA*19; RE19; JAR*16].

The simulations used for the visualizations in this film are also based on the ICON model, and use a globally coupled model setup with an atmospheric and an oceanic component. Both models have a resolution of 5km and are coupled internally to perform a matter and energy exchange. The ocean is simulated with 120 vertical levels, while the atmosphere uses 75 levels. Specifically for these animations, a high temporal output of just 6 minutes was chosen to be able to visualize the daily cycle in different regions of the Earth.

Coupled climate models can generally be considered as multidisciplinary or multi-physics software tools to study the interactions of the atmosphere, oceans, land surface, sea ice and other components of the Earth climate system. Global coupled models have been used for climate simulations since the late 1960s starting with the pioneering work by Syukuro Manabe and Kirk Bryan [MB69]. Since the late 1980s coupled models are in use for century-long simulations, and we observe a rapid and continuous increase of activity in global coupled modelling as additional computer resources become available by increasing the simulated time or, as seen here, by increasing the spacial resolution.

While the DYAMOND++ model setup normally allows the simulation of about 30 days per day utilizing 420 compute nodes, the strong I/O requirements for the high temporal 3D output decelerated the simulation down to only 2 simulated days per day. In total we simulated 10 days, which accumulated to 160TB of data for both the atmosphere and the ocean.

2. Visualization and Rendering

The data was visualized using ParaView, for which we developed a reader that is able to read ICON netCDF and ICON grib compressed data. Prior to the visualization, the data was processed in a way that some parts of the data have been selected, i.e. lake Victoria in Africa, the island of Borneo, the Amazon region, as well as the North Atlantic. This processing was done using the climate data operators (CDO). The data is visualized with ParaView 5.7.1 using the extension Panoramic Projection View, which was developed by Kitware SAS in France in 2018, and more recently extended to also support raytracing using OSPRay and OptiX [WJA*17; PBD*10]. This extension allowed us to directly produce dome format images with a projection angle of 180° in 4096 x 4096 resolution. Internally, the rendering is done using a cubemap where the scene is rendered on 5 different faces of this cubemap, each face having a resolution of 4096 x 4096 pixels.

A first version of the film was created using OpenGL and direct illumination, by utilizing Intel's OpenSWR OpenGL implementation. As for the higher visual quality, we decided to rerender the entire film with OSPRay and pathtracing enabled for all visualizations. The visual quality of the raytracing images are clearly superior, while the rendering time is almost comparable. Pathracing helps especially to improve the 3D perception of a scene and also allows to better differentiate the individual cloud layers. While scene composition was done on classic GPU nodes with OpenGL rendering and OSPRay raytracing, the final rendering took place in batch mode with a MESA/OSPRay ParaView version on up to 25 compute nodes in parallel.

All visualizations show multiple 2D/3D variables, with a slight focus on the interplay between the ocean and the atmosphere. This is especially shown in the visualizations that focus on the island of Borneo, as well as the North Atlantic region, whose atmospheric conditions often influence the weather in Europe. Here the 3D variables liquid cloud water and cloud ice are shown using volume rendering, while the surface layer of the ocean either displays sea surface temperature or salinity, as well as shows sea level pressure using contour lines. The land surface also shows temperature, thereby illustrating the daily cycle of warming though daytime and cooling in the night. The land surface additionally shows evaporation, which is also linked to the daily cycle, as well as wind magnitude. A specific ocean only visualization highlights on sea surface height and its correlation to salinity and temperature, as well as shows sea surface velocity using arrows and in another example using a logarithmic color table.

3. Composition and Editing

While the animations were produced entirely using ParaView, also a real 360° camera was used to record an interview and statements from some of our lead scientists that are involved in the development of both ICON and DYAMOND++. The filming was done using an Insta 360 Pro2, which is able to record full 360° scenes with a resolution of 8k x 4k using 6 high-resolution cameras. The stitching and the conversion to a 180° dome format was performed in a post-processing step using Adobe After Effects.

The final video editing was done using Adobe Premiere, Adobe Audition was employed to enhance and cut the audio recordings. Three songs, licensed from audiohub.de, were used to enrich the atmosphere of the short film. As preview for the dome output we used the free available Amateras Dome Player, which allowed us to project the movie into a virtual dome to assess the correct positions of logos, text segments etc. The composed short film was rendered using Adobe Premiere and Adobe's Media Encoder.

Although initially intended to be shown at the Wisdome Scientific Visualization Contest[†], this 180° VR film can of course also be played back in immersive head mounted displays. While the perception and level of immersion is not the same compared to a full dome setting, it's closer than watching the film on a flat screen.

[†] `https://conferences.eg.org/egev20/wisdome-movie-contest/`

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