

Putting the Ocean into the Center: A coupled ICON Atmosphere/Ocean Simulation in Spilhaus Projection

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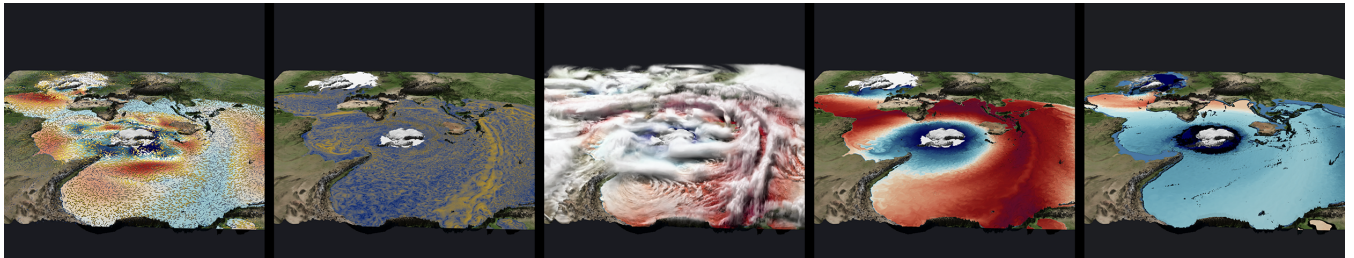


Figure 1: Frames from the Animation: Sea Surface Pressure and 10m Wind, Sea Surface Velocity and Sea Ice, Clouds as Composition of liquid Cloud Water and Cloud Ice, Sea Surface Temperature, and Sea Temperature on an isopycnal Layer.

Abstract

Climate simulations are one of the most data intensive scientific disciplines. We have performed another DYAMOND++ experiment using our globally coupled Earth System Model ICON-ESM, which allows global simulations at a resolution of 5km to study a wide range of Earth’s weather and climate phenomena. The handling of the data and the visualization is not trivial, as in this visualization we look at the full time varying 3D ocean and 3D atmospheric data. The simulation was running for one model year, from which we chose the months May, June and July for visualization.

Opposed to the majority of other global climate visualizations, we explicitly selected the Spilhaus projection to put the oceans into the center and visualize them as one body of water, without cut outs, clipping planes and only minor distortions. We thereby focus on 3D atmospheric and 3D ocean data, and the interaction in between.

CCS Concepts

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

1. Introduction

Last year for the Visualization and Data Analysis Showcase at Supercomputing 2020 we presented visualization results [RBZ*20] that were also based on ICON-ESM. The ICON Earth System Model is jointly developed by the Max Planck Institute for Meteorology (MPI-M), the German Weather Service (DWD) and the German Climate Computing Center (DKRZ). ICON is a framework based on an icosahedral grid for the horizontal layout and uses a rectilinear grid for the vertical setup. It allows for high resolution climate and weather experiments [SSA*19], as well as regional simulations and nested setups. With km scale resolution,

particularly the atmospheric convection, and therefore the development of clouds and precipitation processes can almost explicitly be simulated, while a parametrization of these processes is needed for coarser resolutions. Small scale features such as ocean eddies are now resolved and can be studied in detail. ICON-ESM is part of the Sapphire[†] project at MPI-M with the ambition for hectometer-scale modeling to resolve shallow convection in the atmosphere, as well as sub-mesoscale eddies in the ocean.

[†] <https://mpimet.mpg.de/en/science/modeling-with-icon/ruby-and-sapphire>

In our last year’s entry to the Scientific Visualization and Data Analysis Showcase [RBZ*20], we presented visualized results of an earlier 10-days simulation with the DYAMOND++ ICON model setup as immersive 180° VR-video. In this work, although we visualized 3D atmospheric data, we restricted ourselves to a few local regions only, and also only presented 2D data for the ocean. This year, we show global 3D atmospheric data, as well as global 3D ocean data with a focus on the ocean, and the interaction in between. This year’s DYAMOND++ experiment ran for a whole model year, with hourly 3D output for the first 40 days, and daily output for the remaining days. 2D output was written out at a higher frequency. The amount of data for the entire one year experiment accumulates to 80 TB of data stored as NetCDF files. For our animation, however, we only used the months May, June and July to explain and discuss a number of interesting climate and weather events.

As we wanted to focus on the oceans and put the oceans into the center of the animation, we chose the Spilhaus projection [Spi42; SBK20], which is a bit unusual, but allows us to show the oceans of the Earth connected as one body of water, without intersection, cut outs, clipping planes and with only minimal distortion to the oceanic regions. This projection allows for an interesting new view at the processes governing our climate.

2. Visualization, Rendering and Composing

The data was visualized using ParaView, for which we developed a reader that is able to directly read our simulation output as ICON netCDF and ICON grib compressed data. Last year, this reader was extended – among other things – to also support the Spilhaus projection. This projection gained a lot of interest over the recent years. Originally created by Athelstan Frederick Spilhaus [Spi42] in 1942, this projection was featured in a long article in the ArcGIS forum in 2018 who concluded that the Spilhaus projection is in fact an oblique slice of the Adams World in Square II projection [Spi42]. We added this to our ICON reader in ParaView, and now can import our model output into ParaView directly mapped to *Spilhaus*, aka Adams World in Square II, projection.

Prior to the visualization, the data was processed using the climate data operators (CDO). This processing involved the derivation of a new 3D field describing *Clouds* by optical properties as a composition of the two 3D scalar fields liquid cloud water and cloud ice. The processing also included a resampling of the pressure levels to a rectilinear height representation in meter, as well as the derivation of the 3D variable *Potential Density* for the ocean, which was later used to create an iso-surface as isopycnal layer. An isopycnal layer is a surface in the ocean of equal density, on which most transport processes in the ocean interior take place. Density generally increases with depth, but is also dependent on temperature and salinity, therefore the depth level of this layer varies in the ocean, as can also be seen in the animation. In some places this layer is a few 1000 meters deep below the surface, while in other regions, this layer interacts with the sea surface and is in direct contact with the atmosphere. These are also the areas, in which for example the Labrador sea water (Labrador Sea), and the Antarctic intermediate Water (around Antarctica) is formed.

The data itself is setup and visualized using ParaView 5.7.1. The

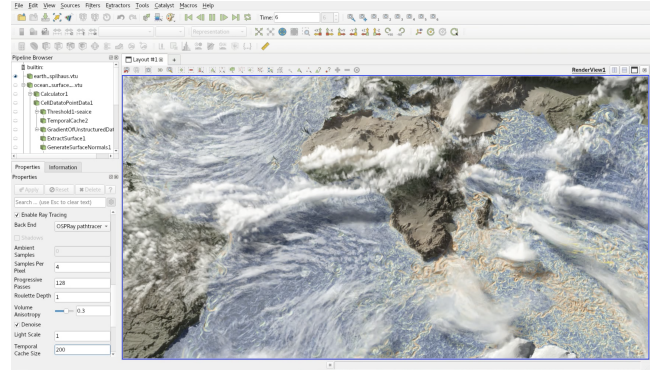


Figure 2: Interactive Visualization of Clouds and Ocean Currents for a Demo at ISC2021.

rendering was performed using OSPRay, one of the two raytracing back ends available in ParaView [WJA*17; PBD*10]. All frames have been rendered with pathtracing enabled, the rendering time per frame (including data handling and processing in ParaView) was between 3 and 5 minutes. In order to accentuate the horizontal ocean velocity, we applied bump mapping to the sea surface layer. Here the magnitude of the flow was computed, and in connection with the ParaView modules *GradientsOfUnstructuredDataSets*, *ExtractSurface*, *GenerateSurfaceNormals* and the *Calculator* module, we bend the surface normals to highlight the horizontal flow field. The film was created in regular full HD resolution with a camera orbiting above the data. The camera thereby either orbits around the entire Earth, or over a smaller section, the North Atlantic, which is used to show some close-ups of the simulation results. One revolution thereby represents the 90 days of the simulation time frame used. And although only full HD PNGs have been written out, due to the large number of different visualizations shown, all rendered images accumulate to about 65GB in size.

The visual quality of the raytracing images are clearly superior. Pathtracing helps to improve the 3D perception of a scene and also allows to better differentiate the individual cloud layers. The scene composition and setup was done on classic GPU nodes with OpenGL rendering and OSPRay raytracing for testing, the final rendering took place in batch mode with a MESA/OSPRay ParaView installation on up to 20 compute nodes in parallel.

All visualizations show multiple 2D/3D variables, with a focus on the ocean and the interplay between the ocean and the atmosphere. Narration was used to explain the many different features and structures that are visible in such high resolution data. The final editing of the film was done using Adobe Premiere and partially also Adobe After Effects, Adobe Audition was employed for recording and filtering the narration. One song that is licensed from audiohub.de is used as background music to enrich the atmosphere of the film.

2.1. Interactive Demo

Additionally to the visualization that was rendered in batch mode on our HPC system Mistral, we also tuned the data for an interactive

showcase using a modern INTEL system for the ISC conference[‡]. Here the pre-processing also involved an optimization of the data, so that it could be read in faster. The demo showcases a live capture of a running visualization of the same simulation data as was used for the film, and is also rendered in ParaView using the built-in raytracing libraries from Intel's oneAPI Rendering Toolkit.

The demonstration shows distributed rendering on a small cluster to showcase OSPRay's scaleable rendering support over multiple nodes. The hardware consists of 10 nodes and uses the Intel Optane as extended memory space. This allows us to load all timesteps into an extended virtual memory buffer beyond the limits of system RAM that is fast enough to render with. Opposed to the longer non-interactive rendering times on Mistral, this approach allowed us to really interact with the data in realtime.

3. Acknowledgements

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[‡] <https://hpcevents.intel.com/demo-hall/advanced-ray-tracing>