THE SIMPLE CLOUD-RESOLVING E3SM ATMOSPHERE MODEL (SCREAM)

The Energy Exascale Earth System Model (E3SM, e3sm.org) project is building a new atmosphere model - the Simple Cloud-Resolving E3SM Atmosphere Model (SCREAM) - capable of using Graphics Processing Unit (GPU) architectures to run efficiently at a global resolution of 3 km cell length. Conventional, low-resolution climate models use grid cells from 25 to 100 km to a side. One key advantage of higher resolution is the ability to capture fine-scale extreme weather events such as atmospheric rivers (Fig. 1), which bring heavy precipitation to the west coasts of North America and northern Europe. Higher resolution is also important for accurately resolving coastal areas and mountainous regions, and for capturing convective clouds, which are a leading source of climate change uncertainty (Sanderson et al., 2008 and Sherwood et al., 2014).

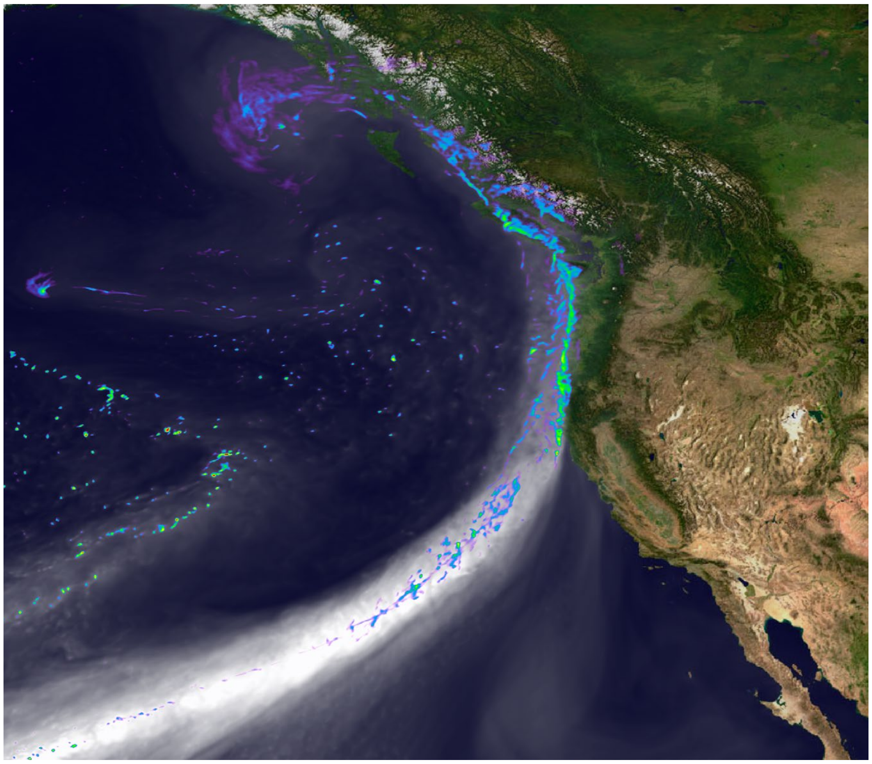

Figure 1. Snapshot of a simulated landfalling atmospheric river along the west coast of North America on February 11th 2020 at 23:00:00 UTC. Grayscale depicts vertically integrated water vapor. Colors indicate precipitation intensity with blue representing weaker rain and green very strong precipitation.

COMPUTATIONAL OPPORTUNITY

A major change in High-Performance Computing is currently underway. GPUs enable revolutionary simulations, but only for applications allowing *simultaneous* computation of huge numbers of calculations and only for codes designed to run on GPUs. Global atmospheric simulations with very fine grid spacing are a perfect application for these new computing architectures. Finer resolution provides an enormous number of columns to parallelize over and as mentioned above, higher resolution solves longstanding problems in climate science.

A NEW MODEL

In June 2018 the E3SM project embarked on the SCREAM effort, which is occurring in two overlapping stages. Stage 1 extends the existing E3SM model to include process representations appropriate for 3 km resolution. The resulting Fortran code is being used to understand the climate of the SCREAM model and to serve as a template for Stage 2, where the code is rewritten in C++ using the Kokkos library (Edwards et al., 2014) to enable efficient simulation on CPUs, GPUs, and future architectures.

Get SCREAM

- DOI – **https://doi.org/10.5281/zenodo.4637766**
- Code – **https://github.com/E3SM-Project/scream**

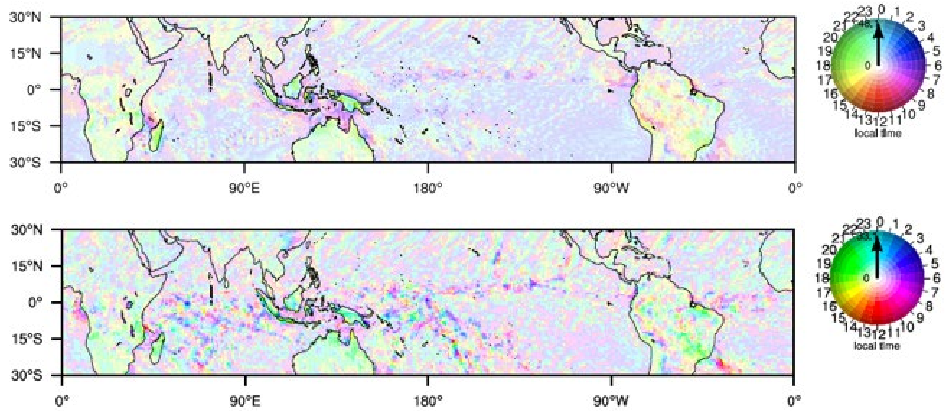

Figure 2. Diurnal cycle of precipitation in SCREAM (top) and Global Precipitation Measurement (GPM) observations (bottom). Hue indicates time of peak precipitation and intensity/level of color saturation depicts the magnitude of the difference between average daily maximum and minimum precipitation at a given location.

The team's first Stage 1 science simulation was a 40-day boreal wintertime simulation (Jan 20th-Mar 1st, 2020) for phase 2 of the DYnamics of the Atmospheric general circulation Modeled On Nonhydrostatic Domains (DYAMOND) Intercomparison (www.esiwace.eu/services/dyamond). This simulation, and SCREAM in general, is described in Caldwell et al. (2021). The model ran at ~5 simulated days per wall-clock day on 1536 nodes of the Cori-KNL computer at the National Energy Research Supercomputing Center (NERSC). This model has 128 vertical levels and a model top at 40 km (compared to E3SM's traditional atmosphere model which has 72 levels with a 60 km top). It has 50 m vertical resolution in the surface boundary layer, 100 m resolution in shallow cumulus heights, and 250 m resolution in upper tropospheric cirrus anvils.

Fine-scale weather events like hurricanes, cold air outbreaks, and atmospheric rivers have a disproportionately large impact on humans but are not captured by conventional global climate models. By resolving fine scale features and their interaction with the larger scale circulation, models like SCREAM fix several classic biases from conventional models even without in-depth tuning. In particular, the vertical structure of tropical convection and coastal stratocumulus compare well to observations, the dry bias over the Amazon is removed, and the frequency of heavy versus light precipitation is much more realistic. The diurnal cycle of tropical precipitation, shown in Figure 2, is particularly impressive. Convection-resolving global models also unlock new types of climate questions related to interaction between small-scale features like convection and topography and their impact on the global circulation.

LOOKING AHEAD

The DYAMOND simulation is just the first step in an ambitious plan. The C++ version of SCREAM should be complete by 2022. This will enable additional, longer simulations. A limited-area version of SCREAM, which simulates a small portion of the globe, is also being finalized. This limited-area version will be much more computationally affordable, making it extremely useful for testing and improving SCREAM physics, particularly via comparison to Atmospheric Radiation Measurement (ARM) data. A separate project called EAGLES (Enabling Aerosol-cloud interactions at GLobal convection-permitting scalES) is developing a prognostic aerosol scheme for SCREAM. Finally, parameterizations appropriate for low resolution are also planned so this GPU-enabled atmosphere model can be used for all E3SM applications by the end of the decade.

SUPPORT

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References: Caldwell, P. M., Terai, C. R., Hillman, B. R., Keen, N. D., Bogenschutz, P. A., Lin, W., Beydoun, H., Taylor, M., Bertagna, L., Bradley, A., Clevenger, T. C., Donahue, A. S., Eldred, C., Foucar, J., Golaz, C., Guba, O., Jacob, R., Johnson, J., Krishna, J., Liu, W., Pressel, K., Salinger, A. G., Singh, B., Steyer, A., Ullrich, P., Wu, D., Yuan, X., Shpund, J., Ma, H.-Y., Zender, C. S. (2021). Convection-Permitting Simulations with the E3SM Global Atmosphere Model. Submitted to JAMES. https://doi.org/10.1002/essoar.10506530.1

Edwards, H. C., Trott, C. R., & Sunderland, D. (2014). Kokkos: Enabling manycore performance portability through polymorphic memory access patterns. Journal of Parallel and Distributed Computing, 74(12), 3202–3216. https://doi.org/10.1016/j.jpdc.2014.07.003

Sanderson, B. M., Piani, C., Ingram, W. J., Stone, D. A., & Allen, M. R. (2008). Towards constraining climate sensitivity by linear analysis of feedback patterns in thousands of perturbed-physics GCM simulations. Climate Dynamics, 30(2), 175–190. https://doi.org/10.1007/s00382-007-0280-7

Sherwood, S. C., Bony, S., & Dufresne, J.-L. (2014). Spread in model climate sensitivity traced to atmospheric convective mixing. Nature, 505(7481), 37–42. https://doi.org/10.1038/nature12829

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