APPLICATION BRIEF

FMI Researchers Run the Vlasiator Code on the Cray® XC30™ Supercomputer and Get Outstanding Results

Organization

Finnish Meteorological Institute
Helsinki, Finland
http://en.ilmatieteenlaitos.fi/

FINNISH METEOROLOGICAL INSTITUTE

About FMI

The Finnish Meteorological Institute (FMI) is a governmental research institute providing the national weather service in Finland. Additionally, FMI conducts research across a range of science activities including air quality, space research, climate change and polar research. The institute is also the only one in Europe to possess all types of space plasma simulation models and is one of the top research organizations worldwide in simulating solar system plasma environments.

CSC and 'Sisu'

FMI researchers conducted their Vlasiator simulation code work on "Sisu" — a Cray® XC30™ supercomputer hosted by the Finnish IT Center for Science Ltd. (CSC). CSC is Finland's national high performance computing facility supporting research in a wide range of fields including climate change, energy research, materials science, gene interactions and medical research. Sisu is Finland's flagship supercomputer and the region's fastest system with a peak performance of 1.7 petaflops.

System Specifications

- System: Cray XC30
- Cabinets: 9
- Peak performance: 1.7 PF
- Compute nodes: 1,688, each with two Intel® Xeon® E5 12-core processors
- Compute cores: 40,512
- Memory: 64 GB per node
- Interconnect: Aries

"Sisu was extremely stable with not a single failure when running long simulations on the full machine."

—Dr. Sebastian von Alfthan
Head of Group
Model Development & Space Innovations
Finnish Meteorological Institute

Situation

Vlasiator is a groundbreaking space plasma simulation code developed at the Finnish Meteorological Institute (FMI). Specifically, it simulates the dynamics of plasma (ionized gases) in near-Earth space using a finite volume method solver for the hybrid-Vlasov description. In this model, protons are described by a 6-D distribution function embedded in a self-consistent solution of electromagnetic fields in 3-D ordinary space.

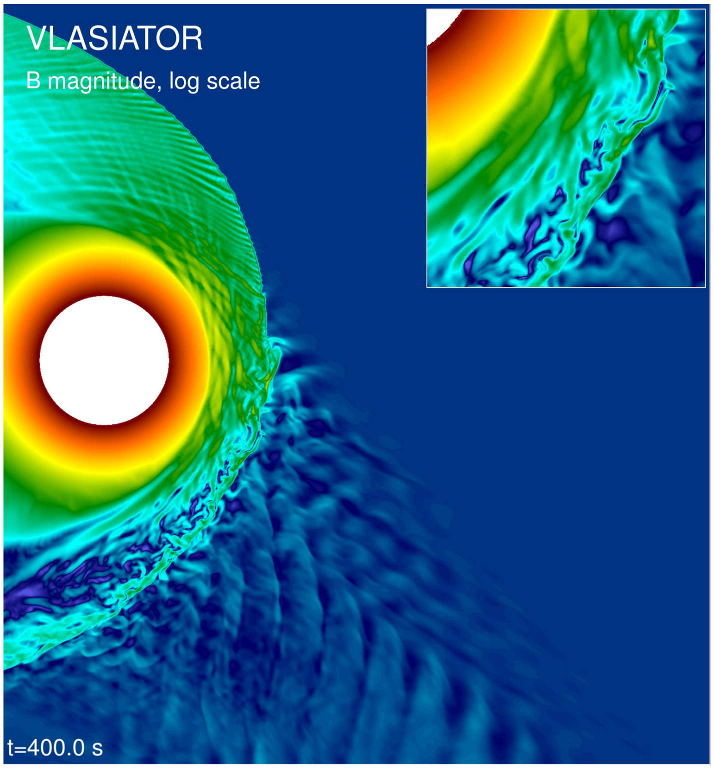
But what makes the code so groundbreaking is its ability to model space weather with an accuracy comparable to spacecraft measurements. The near-Earth environment is highly complex and therefore extremely difficult to simulate. It is dominated by the interactions between the solar wind — a highly variable stream of charged particles carrying the solar electromagnetic field — and Earth's magnetic field. The complexity of this environment is coupled with an urgent need to understand it. Solar flares and coronal mass ejections create space weather, which can cause blackouts on Earth and other harmful effects.

Vlasiator is the world's first code to capture large simulation volumes with extremely detailed physics using a kinetic theory. However, this approach requires large supercomputing resources. Each simulation typically requires tens of thousands of cores.

Results

Using a Cray® XC30™ supercomputer featuring Intel Xeon E5 "Haswell" processors and hosted by the Finnish IT Center for Science Ltd. (CSC), researchers were able to run Vlasiator on an unprecedented 40,000 cores. The new semi-global simulations included the shock front encompassing Earth's magnetic field and its surroundings.

The XC30 system "Sisu" allowed them to simulate this setup with four times better resolution than ever before, with a solver that includes all the relevant ion-scale physics. Vlasiator revealed that the shock front is much more complex than previously thought and provided a new paradigm for interpreting the wave formation that had not been adequately explained earlier.



UNPRCEDENTED RESOLUTION: The color coding in this image illustrates the magnetic field in interaction with the solar wind within the near-Earth region. The stream of solar wind blows from the right, and Earth's magnetic field sits within this stream like a rock in a river. The stream is deflected by Earth's magnetic field, and a shock front forms to encompass its magnetic domain. The simulation produced incredibly fine structured and turbulent sheath plasma with never-before-achieved detail. The wave field in the lower right is due to instability between the solar wind particles and particles that reflect at the shock surface.

Image courtesy of Finnish Meteorological Institute

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These simulations were enabled by the excellent scalability of the Cray XC30 architecture. Vlasiator is parallelized with a hybrid MPI-OpenMP scheme, where 3-D ordinary space is parallelized with MPI while 3-D velocity space is further parallelized using OpenMP. Additionally, researchers use a third parallelism level — solvers operate on vector data types directly mapping to AVX vectors. Even with Vlasiator's highly dynamic data structures describing the sparse distribution function, researchers still achieved over 10 percent of peak flops. At the same time they saw excellent scalability. Per node performance only dropped by 30 percent when scaling from 1,000 to 40,000 cores.

For more information about the work on the Vlasiator code, please visit http://vlasiator.fmi.fi

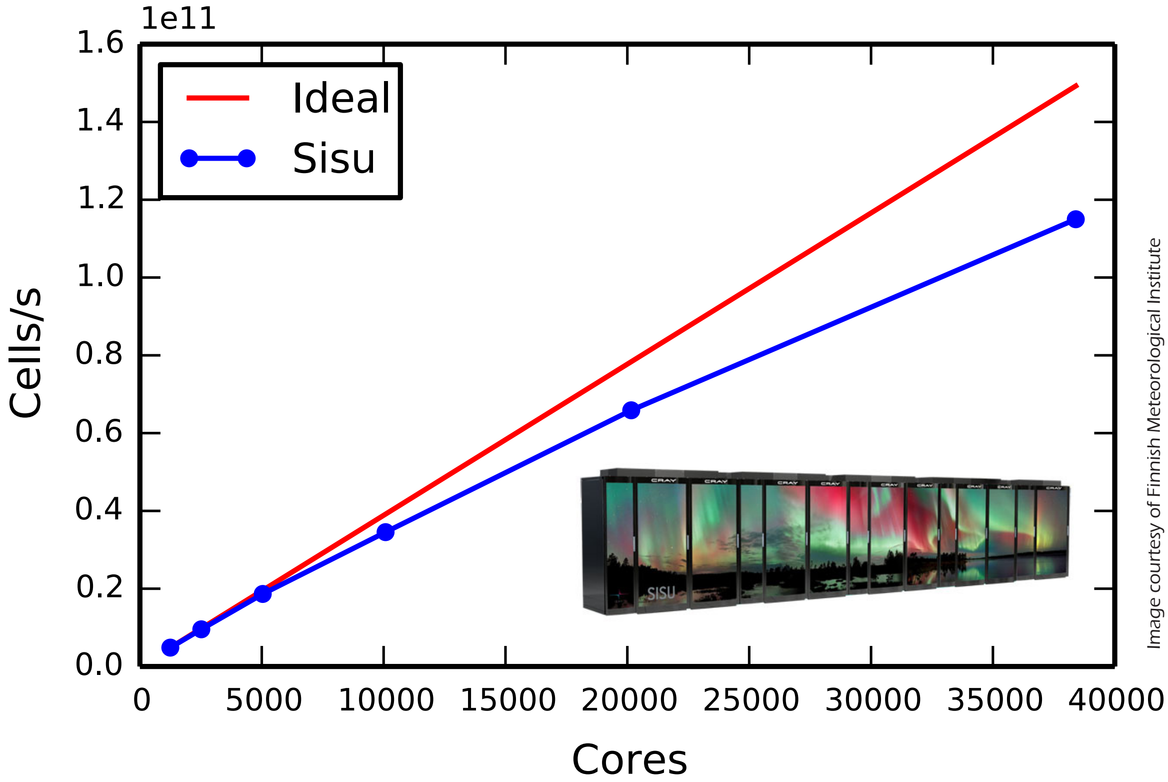

Image courtesy of Finnish Meteorological Institute

SCALABILITY: The Cray XC30 "Sisu" supercomputer showed strong scalability on the Vlasiator space plasma simulation code. Per node performance only dropped 30 percent when scaling from 1,000 to all of the system's 40,000 cores.