High Performance Computing

Case Study.

Learning to Cope With the Sun's Stormy Weather Using High Performance Computing

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Learning to Cope With the Sun's Stormy Weather Using High Performance Computing

Researchers at Science Applications International Corporation in San Diego have been studying the sun's corona and its impact on space weather for well over a decade. Advances in their understanding of the physics of solar activity, made possible by the use of supercomputers at the nearby NSF-funded San Diego Supercomputer Center, have allowed them to move from one-dimensional models of solar flares and coronal mass ejections to 3-D models that can more accurately predict the impact of these phenomena on weather in space. Space weather can have a major impact on Earth's power grids, communications, satellites and other essential systems.

It's no wonder the Egyptians worshiped the sun god Ra. His daily chariot ride across the heavens brought warmth, food and life itself. You can only wonder how they would have regarded their primary deity if they had been privy to a telescope or two, a few satellites, an unmanned spacecraft, a supercomputer and the Egyptian equivalent of Jon Linker.

Linker, director of the Center for Energy and Space Sciences at Science Applications International Corporation (SAIC) in San Diego has been studying the sun for 20 years. He and his colleagues at SAIC developed the first accurate digital map of the corona (the sun's outermost layer, a low density cloud of plasma that is only visible during a solar eclipse). With the help of supercomputers at the San Diego Supercomputer Center (SDSC), the SAIC team had developed models of the corona's appearance and behavior that were confirmed during the total solar eclipse on March 29, 2006.

SAIC is a leading provider of scientific, engineering, systems integration, and technical services and products to all branches of the U.S. military, various government agencies and selected commercial customers. With revenues of $8.3 billion in FY2007, the company has more than 44,000 employees and offices in more than 150 cities worldwide.

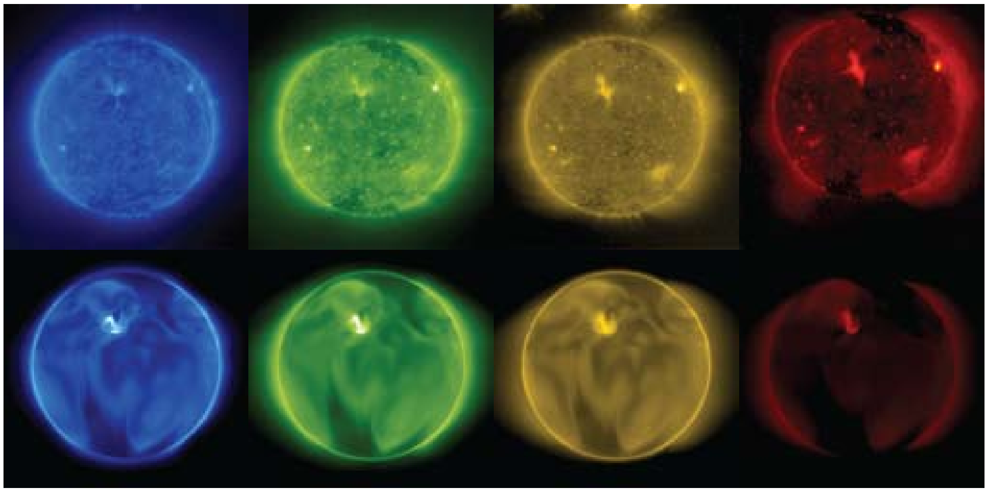
Among the many services SAIC offers is leading-edge research and development that includes investigations into solar activity that can adversely impact both people and technology. These explorations are pushing the limits of what can be accomplished with high performance computing (HPC).

Tracking Potentially Deadly Solar Flares and Coronal Ejections

Linker and his colleagues at SAIC's Center for Energy and Space Sciences are attempting to model weather patterns that would boggle the minds of terrestrial weather forecasters. But it's not likely you'll see their forecast anytime soon on your evening news. The SAIC team is working with a much larger canvas – the weather in space.

"Our research is an attempt to model the sun's corona in order to more accurately predict the appearance, strength and location of solar flares and coronal mass ejections," Linker explains. "This 'space weather' – what happens when these solar storms travel through space and impact the Earth's magnetosphere – has important ramifications for our national economy, defense systems, power grids, space exploration, and many other aspects of our day-to-day life."

Space weather can be just as disruptive as terrestrial



The blue, green and gold images of the sun's corona in the top row were taken with the Extreme Ultraviolet Imaging Telescope on the orbiting Solar and Heliospheric Observatory. The red image was taken with the Soft X-ray Telescope aboard the Yohkoh spacecraft. The bottom images are from simulations of the sun's corona that were accomplished on high performance computers at SDSC and NASA Ames. Note the similarity between the actual images and the simulated images.

storms like tornadoes and hurricanes. When a coronal mass ejection – a violent eruption from the sun of billions of tons of hot electrified gasses – nears the Earth, it can compress the magnetosphere, our planet's magnetic shield. Satellites are suddenly exposed to a torrent of charged particles that can knock out their electronics, disrupting communications. GPS signals can be distorted and provide inaccurate positioning readings. Power grids can be damaged – in fact, space weather is blamed for the vast outage that hit Quebec in March 1989, when a multimillion-dollar transformer was fried and thousands of people lost power. Other storms have caused satellite problems. In May 1998, a period of elevated space weather may have disabled the Galaxy IV satellite, taking out ATMs, gas station credit card handling services, 80 percent of all pagers in the United States, news wire service feeds, CNN's airport network and some airline weather tracking services. And in 2003, a series of 17 solar flares damaged computer circuits on more than half of NASA's satellites and space probes. Three Department of Defense surveillance satellites were knocked out of commission, and an expensive Japanese observation satellite permanently ceased transmitting.

Energy and radiation from solar flares and coronal mass ejections can harm astronauts in space and play havoc with the electronic infrastructure that we have come to depend on for business, defense and lifestyle. Airlines are monitoring space weather to minimize the amount of time their crews and equipment spend in the more exposed polar regions during an upsurge in geomagnetic activity.

Given the impact of space weather on practically every aspect of our lives, it's no wonder that the SAIC researchers feel a sense of urgency in their attempts to understand the complex behavior of the sun's corona and make it possible to accurately predict when a burst of harmful space weather is headed our way.

Understanding the Sun's Complex and Violent Corona

X-ray or extreme ultraviolet pictures of the sun reveal that the corona is not the fuzzy halo of gasses that is often portrayed. It is actually laced with huge loops of plasma resembling gigantic, glowing rubber bands that outline the magnetic field. The magnetic loops generated at the sun's core can become twisted and tangled. When these tangles snap, a torrent of energy is released in the form of a solar flare or a coronal mass ejection.

The study of these loops and the sun's magnetic field is called magnetohydrodynamics (MHD). The modeling of this intense solar activity, which advances our understanding of the corona and space weather, is as computationally intensive as any science today, requiring the most powerful supercomputers.

In the past, the complicated physics involved and the amount of computer time required to solve these MHD equations had pretty much limited scientists to making one- and two- dimensional models of coronal activity. These models are very helpful and provide a great deal of important information. But the sun and its loops are 3-D. During the past several years, Linker and his colleagues have been attempting to solve these detailed energy equations to model the transport of heat in the corona on this much larger 3-D scale. This creates a whole new set of computational challenges. So they turned to SDSC for assistance. SDSC is one of several university supercomputing centers supported through the National Science Foundation (NSF) to provide HPC

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Jon Linker, director, Center for Energy and Space Sciences, Science Applications International Corporation

capabilities to researchers across the country.

A one-dimensional model uses thousands of grid points and can run on today's workstations. But a 3-D model that provides the same resolution would require tens of billions of grid points or more, far beyond the computational capabilities of even the most advanced supercomputers. However, the high-powered supercomputers at SDSC have the capability to handle MHD calculations involving as many as 20 million grid points. Says Linker, "We can still get a very accurate 3-D model of the corona if we are clever about how we resolve calculations that describe its various characteristics. "

Benefits of HPC: New Questions, New Answers

Linker says supercomputer resources have been essential to tackling problems that researchers would never have dreamed of attempting in the past. "Our work can be viewed as a progression made possible by advances in our understanding of how to model the sun's energy flow and the advanced supercomputers that make those calculations possible.

"Twelve years ago, using the supercomputers at SDSC, for the first time we were able to predict what the white light corona would look like during an eclipse," he continues. "That was unprecedented. Today those calculations are being done on workstations. Now the team is building a model of a coronal mass ejection that details how the magnetic field lines light up or dim in extreme ultraviolet. This will provide important information about the actual physics involved and aid in the ultimate goal of making earlier, more accurate predictions of the weather in space."

He notes that although excellent progress is being made in understanding the sun's coronal activities, the team is only at the beginning of their investigations. "The environments that we're studying are extraordinarily complex. Our challenge is to make even more detailed computational models to try to understand what's going on. We are attempting to make a reasonable approximation of the physics involved to create even more accurate models of the corona. But we could use far more computing power than is available today."

The SAIC team has a reputation for pushing the envelope – moving into uncharted territory to create better approximations of solar phenomena. As SDSC and other NSF HPC centers continue to add computational capability, those approximations will allow SAIC to create models that will give them an even better understanding of the corona and its impact on space weather. This in turn will allow scientists to better predict when solar flares and coronal mass ejections are likely to threaten orbiting satellites and communications and power systems on Earth.

Linker comments, "If you ask somebody who knows a little bit of astronomy, 'What's the closest star to Earth?' they will probably answer Proxima Centauri, which is about 4.2 light years away. They would be wrong. The closest star to the Earth is the sun. Because this star impacts our lives in so many ways, it seems obvious to me that we need to understand as much as we can about this body. And there's something else. Astronomers estimate that there are over 100 billion stars in the Milky Way, and at least 70 sextillion (7×1022) stars in the observable universe. Many of the same processes that we observe on our sun are occurring in billions and billions of galaxies. By learning more about our star, we increase our understanding of the universe."

In Brief

Key Challenges

- More accurately predict the intensity and duration of solar flares and coronal mass ejections in order to anticipate potentially destructive space weather
- Open up new avenues of solar research to better understand the behavior of others stars and the universe

Solutions

- Move from one-dimensional computational models of the sun's magnetic activity to complex 3-D models, using as many as 20 million grid points to conduct studies of the tangled magnetic fields on the star's surface
- Access the high performance computing resources at the San Diego Supercomputer Center to supplement lower level in-house computing capabilities and accelerate the research

Key HPC Benefits

- Creates increasingly accurate models of solar flares and coronal mass ejections that are expanding scientific understanding of the appearance, duration and intensity of solar storms that can impact the Earth's magnetosphere
- Provides information that can be used to monitor space weather and lessen the damage and disruption caused by energy and radiation from solar flares to the national economy, defense systems, power grids, communications systems and electronic devices
- Pushes the scientific envelope to better understand existing problems and tackle new problems that even a few years ago would not have been attempted

Web Site

- www.saic.com

Instead of using 100% virgin paper, we used paper that has been 30% Post-Consumer Recycled and made with 100% wind-generated electricty. We saved:

5 trees preserved for the future
1,667 gal of water flow saved
276 lbs of solid waste not generated
509 lbs of greenhouse gasses prevented
3 million BTUs of energy not consumed

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