The Current Status of the Earth Simulator

After five years' development, the Japan Marine Science and Technology Center empowered the Earth Simulator on March 1, 2002. The Earth Simulator is a highly parallel vector supercomputer system consisting of 640 processor nodes connected by high performance interconnection network switch system. It achieved 35.86 Teraflops (Tflops) in LINPACK benchmark test in May 2002 (Table 1). That was about 90% of its peak performance of 40.96 Tflops. As a result of this extraordinary achievement, in June 2002, the TOP500 project (http://www.top500.org/) formally acknowledged the Earth Simulator as the fastest supercomputer in the world. The Earth Simulator remains the first place of the TOP500 list in November 2003.

For practical applications with average sustained performance of 30% of peak, the Earth Simulator has produced epoch-making results such as simulation of Kuroshio, Gulf Stream and Agulhas Ring in global oceanic circulation; typhoons and rain fronts in global atmospheric circulation; reproduction of whole-earth seismic wave fields in solid earth physics; super-diamond material of carbon-nano-tubes in material science.

Figure 1 shows the sustained performance parameters of the projects running on the Earth Simulator in 2002. The top three performers were honored with the 2002 Gordon Bell Awards.

The Gordon Bell Award for Peak Performance was given to "A 26.58 Tflops Global Atmospheric Simulation with the Spectral Transform Method on the Earth Simulator" [1]. The project hit its peak performance of 26.58 Tflops (65% of the peak value of 40.96 Tflops) using the AFES code with a horizontal resolution of 10 kilometers, a global atmospheric circulation code which was carefully optimized for the Earth Simulator architecture. Also "14.9 TFLOPS Three-dimensional Fluid Simulation for Fusion Science with HPF on the Earth Simulator" [2] was given the Award for Language. The Gordon Bell Award for special accomplishment went to "16.4-Tflops Direct Numerical Simulation of Turbulence by a Fourier Spectral Method on the Earth Simulator" [3]. Moreover, in 2003, the project in solid earth physics "A 14.6 billion degrees of freedom, 5 Tflops, 2.5 terabyte earthquake simulation on the Earth Simulator" [4] won the Gordon Bell Award for Peak Performance.

Even though these peak performances are record-breaking, the Earth Simulator is expected to play one crucial role for altering landscape of science rather than just for high performance computing.

The role is to enable a 'holistic' approach to modeling the evolving natural processes, dealing consistently with a myriad of inter-related factors.

Since the appearance of reductionism by Descartes and Newton in the 17th century, science has been directed towards breaking down the whole into pieces in order to understand nature and its process, principles, and rules composed of basic factors.

The scientific community now faces difficulties in reconstructing and understanding the whole earth system from constituent elements, because each variable turns out to be complexly interconnected to all others and because reductionism often rules out those interactions for the sake of computational simplicity.

Furthermore, modern science has had to assume that natural systems seek or tend to reach equilibrium.

Table 1 Theoretical and sustained performances of the Earth Simulator

Theoretical Performance

Computational Performance

Total	40 Tflops
Per Processor Node	64 Gflops
Per Processor	8 Gflops

Data Transfer Rate between Processor Nodes

Total	7.872 TB/s
Per Processor Node	12.3 GB/s x 2

Sustained Performance

Program	Performance	% of Peak
Linpack HPC	35.86 Tflops	87.5
Bandwidth of MPI	11.8 GB/s	95.9

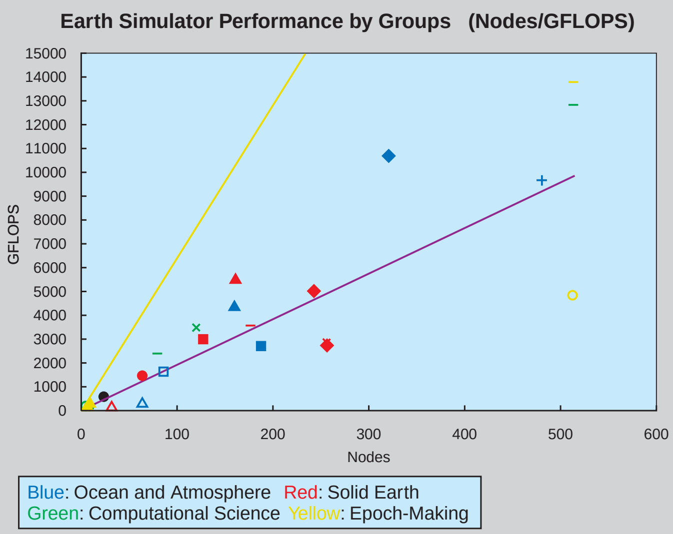

Figure 1 Theoretical and sustained performances of the Earth Simulator. The Yellow line indicates the theoretical peak, the pink line indicates 30% sustained performance. The top three were honorees of the Gordon Bell Award 2002.

However, in reality, nature is an open system. This means energy is unevenly distributed, and is constantly cycling constituent elements of the open system, so that the whole system is probably in disequilibrium.

To grasp an entire system in non-equilibrium and unstable state, it is necessary to incorporate all interactions between the elements into the whole system simultaneously. This is, however, a computationally demanding task.

Using the capabilities of supercomputers, it may be possible to simultaneously and holistically model the interrelated variables comprising the whole-earth system. Examples of the integration on the macro- and microscopic scales include such efforts as the ongoing simultaneous modeling of atmospheric circulation couples with the physics and chemistry of cloud and snow formation. Thus the foundations of a holistic simulation program have been laid. This holistic simulation is a virtual means for revealing the true essence of non-equilibrium/ nonlinear/ open systems, an area which has been left unexplored by 20th century science.

The Earth Simulator may provide a tool for the prediction of global environmental change. This directly influences our daily lives.

How will mass consumption, such as automobiles, airplanes, electric devices and chemical products which we have created, influence the future global environment?

Although humanity has been faced with various forms of highly episodic events such as earthquakes, typhoons, hurricanes, volcanic eruptions or other natural disasters, these have never been a means to accurately predict future occurrences.

The Earth Simulator as a tool for holistic simulation of the entire earth system may enable accurate prediction of the future by modeling of present conditions based on the past data.

This effort will contribute to the protection of people's lives and property from natural disasters and environmental destruction, and may help enable a more harmonious relationship with our only home planet Earth.

(by T. Sato)

References

[1] S. Shingu, H. Takahara, H. Fuchigami, M. Yamada, Y. Tsuda, W. Ohfuchi, Y. Sasaki, K. Kobayashi, T. Hagiwara, S. Habata, M. Yokokawa, H. Itoh, and K. Otsuka, A 26.58 Tflops Global Atmospheric Simulation with the Spectral Transform Method on the Earth Simulator. *Proceedings of the ACM/IEEE SC2002 conference*, 2002. http://www.sc-2002.org/paperpdfs/pap.pap331.pdf.

[2] H. Sakagami, H. Murai, Y. Seo and M. Yokokawa, 14.9 TFLOPS Three-dimensional Fluid Simulation for Fusion Science with HPF on the Earth Simulator. *Proceedings of the ACM/IEEE SC2002 conference*, 2002. http://www.sc-2002.org/paperpdfs/pap.pap147.pdf.

[3] M. Yokokawa, K. Itakura, A. Uno, T. Ishihara and Y. Kaneda, 16.4-Tflops Direct Numerical Simulation of Turbulence by a Fouier Spectral Method on the Earth. *Proceedings of the ACM/IEEE SC2002 conference, 2002*. http://www.sc-2002.org/paperpdfs/pap.pap273.pdf.

[4] D. Komatitsch, S. Tsuboi, C. Ji, and J. Tromp, A 14.6 billion degrees of freedom, 5 teraflops, 2.5 terabyte earthquake simulation on the Earth Simulator, *Proceedings of the ACM/IEEE SC2003 conference*, 2003. http://www.sc-conference.org/sc2003/paperpdfs/pap124.pdf.