Earth Simulation on the Earth Simulator

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Earth Environment System

[Diagram depicting various components of the Earth Environment System, including the atmosphere, land, ocean, and human activities, with arrows indicating processes such as photosynthesis, greenhouse effect, precipitation, and carbon cycle.]
Today’s talk

- **What is the Earth Simulator?**
- **Gift from the Earth Simulator**
  - High resolution simulation Impact
  - Synoptic scale impact
    - Heat wave … “Silk Road Patterns”
  - Cloud resolve-Synoptic scale extreams
    - Typhoon … multi-scale simulations
  - Climate change projection
    - Global Warming … contribute to IPCC report
  - Solid earth simulation
    - Earth quark … Wave Propergation forecasting
  - Aurora arc simulation
    - Toward advanced simulation methodology
- **Next stream in future**
The Earth Simulator

- Development of ES started in 1997 with the aim of making a comprehensive understanding of global environmental changes such as global warming.

- The Kyoto Protocol was opened for signature on 11th Dec. 1997.

- Developed in Mar. 2002 by STA (MEXT) and NEC with 400 M$ investment.

- Project had been strongly promoted under Dr. Miyoshi’s direction. (Dr. Miyoshi: Passed away in Nov. 2001.)

- Its construction was completed at the end of February, 2002.

- The operation started from March 2002 at the Earth Simulator Center in Japan Agency for Marine-Earth Science and Technology (JAMSTEC).

Mission of the Earth Simulator Projects

**ENVIRONMENT**
Protection of lives and properties from natural disasters and environmental destruction

**INDUSTRY**
Huge cost reduction in innovative technology development which requires massive investments

**SCIENCE**
Development of innovative research tools attaching far-from-equilibrium, nonlinear and open systems

**HUMAN**
Paradigm shift to global, future-oriented way of thinking
Location of Earth Simulator Facilities

Tokyo

Earth Simulator Site
The Earth Simulator

- Hard Disk
- Process Nodes
- Tape Archive System
- Connection Network
- Air Conditioning
- Power Supply
- Free Access Floor

Dimensions:
- 65m
- 50m
The Earth Simulator

Hard Disk
Tape Archive System
Process Nodes
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Hard Disk

Process Nodes

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Dimensions:
- 65m
- 50m
Earth Simulator Building

Peak Performance: 40 TFlops
Main Memory: 10 TBytes
Magnetic Disk & Tape: 2.5 PBytes
Configuration of the Earth Simulator

- Peak performance/AP: 8Gflops
- Peak performance/PN: 64Gflops
- Shared memory/PN: 16GB
- Total number of APs: 5120
- Total number of PNs: 640
- Total peak performance: 40Tflops
- Total main memory: 10TB

Interconnection Network (full crossbar switch)

Mass Data Processing System (MDPS): 2.5PB
Network System

Yokohama Institute-Network

ES-Network

SuperSINET (October, 2004)

FTP

MDPS Server

ES-LAN

Earth Simulator

Graphic WS

BRAVE

Data Handling WS

Login Server

MDPS
Allocation of ES resources for 2006

Strategic Project:
- International cooperation
- Industrial application
- etc

Earth Science:
- Climate Change
- Solid Earth
- Natural Disasters

Innovative Project:
- Space and Astrophysics
- Atomic Energy
- CFD Application
- Nano Technology
- BioChemistry
- etc

Government Project:
- IPCC Contribution
- etc

Computer Science:
- Next Generation Algorithm
- Next Generation Architecture
- Next Generation Programming Language
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<th>Country</th>
<th>Institution</th>
<th>Research Area</th>
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<td>USA</td>
<td>SCRIPPS INSTITUTION OF OCEANOGRAPHY UNIVERSITY OF CALIFORNIA, SAN DIEGO</td>
<td>Development of high resolution reanalysis data</td>
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<td>France</td>
<td>THE INSTITUT FRANÇAIS DE RECHERCHE POUR L'EXPLOITATION DE LA MER (IFREMER)</td>
<td>Impact of convective system in equatorial area of ocean</td>
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<td>UK</td>
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<td>USA</td>
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<tr>
<td>USA</td>
<td>THE UNIVERSITY OF TEXAS AT AUSTIN</td>
<td>Advanced Visualization Method for tera–bite scale data</td>
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<tr>
<td>USA</td>
<td>DEPARTMENT OF GEOLOGY &amp; GEOPHYSICS, UNIVERSITY OF MINNESOTA (DGG/UMN)</td>
<td>Advanced Visualization Method for tera–bite scale data</td>
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<td>USA</td>
<td>OF ALASKA FAIRBANKS</td>
<td>Development of advanced polar region modeling</td>
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<tr>
<td>Singapore</td>
<td>INSTITUTE OF HIGH PERFORMANCE COMPUTING</td>
<td>Development of advanced computational methods</td>
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<td>Taiwan</td>
<td>NATIONAL APPLIED RESEARCH LABORATORIES</td>
<td>High resolution weather forecasting modeling</td>
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Impact of Ultra High Resolution Simulation for Global Atmosphere Global Ocean
Typhoon Simulation
300 km vs. 10 km

Horizontal resolution: 300 km

Horizontal resolution: 10 km
Comparison of the Kuroshio Current
100 km vs. 10 km

horizontal resolution: 100 km

Horizontal resolution: 10 km
A Global Atmospheric Circulation Simulation with a horizontal resolution of 10 km
A Global Oceanic Circulation Simulation
with a horizontal resolution of 10 km

Sea Surface Temperature: Time counter = 136 days (15/MAY)

75S–75N, Resolution: 0.1 degree for horizontal, 54 levels for vertical
1500 cpus (188 nodes) used
Antarctic Flow Simulation
10km resolution in the horizontal

Velocity Magnitude(cm/s) at 100m (D/Y = 5 /50)
Synoptic scale impact
Heat wave … “Silk Road Patterns”
Temperature distribution on July 20, 2004

Simulation
Hydrostatic AGCM: AFES

Observation
Japan Meteorological Agency
High Pressure development resulting from meandering Westerly

“Silk Road Pattern”

Near-surface Temperature

Simulation of the Heat Wave in Tokyo Area in July 2004
Impact of Cloud resolving scale – Synoptic scale Simulation
How strong will be extreme under Global Warming?
Cloud Effect and Weather/Climate

- Incoming shortwave radiation
- Absorption/reflection/scattering by atmosphere
- Absorption/reflection/scattering by clouds
- Diffuse solar radiation
- Absorption/reflection by earth's surface
- Earth-emitted longwave radiation

The COMET Program
Cloud Effect and Weather/Climate

- Incoming shortwave radiation
- Absorption/reflection/scattering by clouds
- Absorption/reflection by earth’s surface
- Diffuse solar radiation
- Earth-emitted longwave radiation

About 10km

O(100)m
Cloud Effect and Weather/Climate

Not only impact to external but also to climate change through radiation processes
Scientific Gland Challenge

Impact of
Cloud Scale Synoptic Scale
Weather Climate Change

Requirements:
Long Integration with Ultra High Resolution
+
Various components
e.g. Atmosphere-Ocean Interaction (at least)
Multi-Scale Simulator for Geoenvironment (MSSG)

Seasonal ~ Annual Prediction
5-40 km for horizontal, 100 vertical layers

Urban Weather / Climate Prediction
10m ~ 2km for horizontal, 200 vertical layers

(Data: Geographical Survey Institute)

Scalability

Days ~ Weeks Prediction
Local heavy Rain Prediction, etc.
1 ~ 5km for horizontal
100 vertical layers
5 Days Forecasting of Typhoon 10 of 2003
MSSG, non-hydrostatic Global Ocean-Atmosphere Coupled Simulation

Horizontal resolution: 2.7 km
Vertical resolution: 72 layers
Sea Surface Temperature after Typhoon 11 tracking (2005)


Aqua, NASA
Sea Surface temperature averaged for 5 days (24th August ~ 28th August)
Sea Surface Temperature after Typhoon 11 tracking (2005)


Aqua, NASA
Sea Surface temperature averaged for 5 days (24th August ~ 28th August)
Rainfall Prediction associated with Typhoon 10
Accumulated rainfall of 54 hours of August 7-9, 2003

Observation:

Global with 5.5 km resolution

Nested with 1.15 km resolution
Global Warming
Global Warming Simulation for IPCC AR4

CREAPI (Japan) and NCAR: National Center of Atmospheric Research (USA)

Global Annual Surface Temperature

A1B 750ppm:const

B1 550ppm:const

- A1B scenario... gradually up
- overshooting scenario... gradually down and constant
Change of Precipitation in Summer Season under Global Warming

Center for Climate System Research (CCSR), University of Tokyo
National Institute of Environment System (NIES)
Frontier Research System Center (JAMSTEC)

After 70 years from now, averaged precipitation will be increasing. Global averaged temperature will be up of 2.5°C.
Earthquake
Tokyo beneath M7 Earthquake
Prof. Furumura (Univ. Tokyo)

Domain: 85km × 90km × 102km
(Resolution: 50m, 6.3G meshes)

Crust: sedimentary and rocky

CPU: 1 hour

Seismic wave propagation

Kumagaya
Shinjuku

100 cm

Prof. Furumura (Univ. Tokyo)
Formation of aurora arcs obtained by simulation

from the satellite

from the ground
Simulation of Aurora Arc Formation
(Sun-Magnetosphere-Ionosphere interaction)

Micro-instability
Formation of Double Layer
the energy spectrum of accelerated precipitating electrons

Aurora Arc formation
Magnetic field lines
Calculate aurora brightening by oxygen and nitrogen excitation by energized precipitating electrons

Down-going electrons

Magnetosphere Convection

Up-going electrons

100,000,000 m (macroscopic scale)
Streams to the Near Future

• Multiscale-Multiphysics Simulations

Earth Simulator provides us

» First step to Multi-scale/physics simulation
» Obtained the tool
» Next perspectives to the future
» Realistic feelings/motivations by researchers
» Further advanced simulation Science

Impact of Extremes:
Typhoon, Hurricane ↔ Atmospheric Dynamics
Heavy rain, Draut ↔ Ocean Heat Content
: Climate Change

On NEXT Generation Peta-scale Supercomputing System
In the National Project promoted by RIKEN
Thank you.