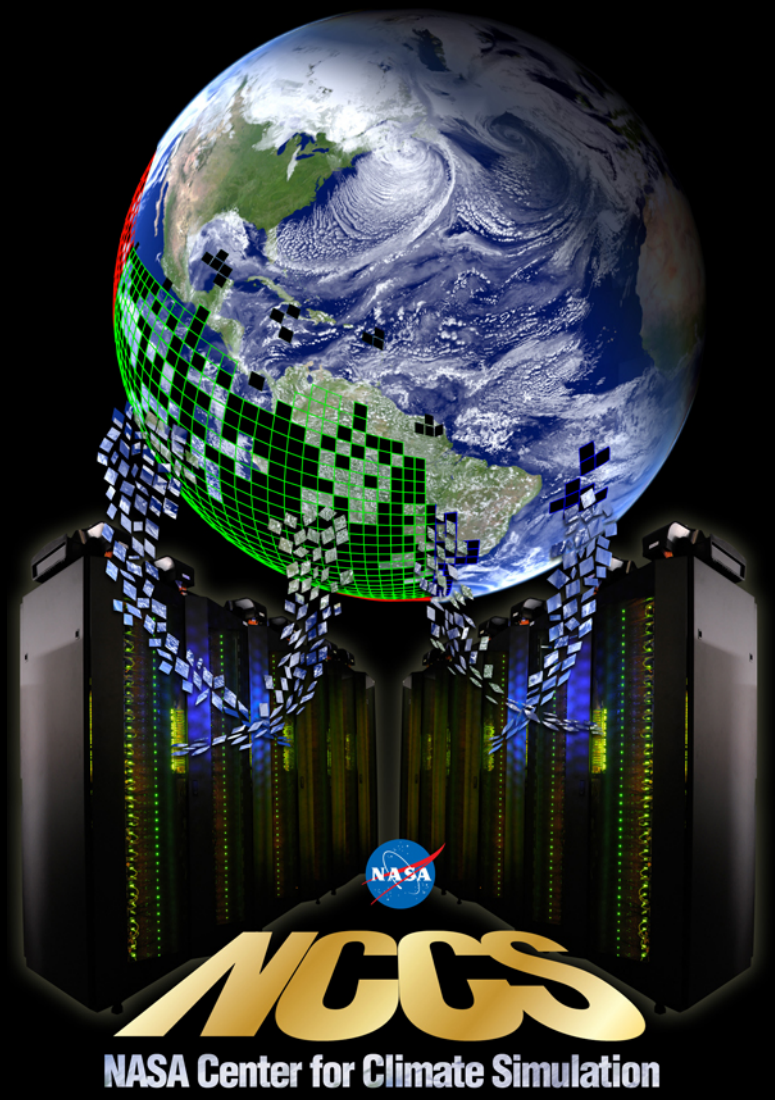


Supercomputing the Climate

Dr. Phil Webster
Chief, Computational and Information Sciences and Technology Office
NASA Goddard Space Flight Center

Parts of a Personal Computer

- Processing
- Memory
- Disk Storage
- Archive
- Monitor
- Input

Parts of a Supercomputer

- Processing
- Memory
- Disk Storage
- Archive
- Monitor
- Input
- Network and Cluster OS

Processing and Memory

"Discover" Supercomputer

- 1.121 petaflops peak = 1,121,000,000,000,000 floating-point operations per second
- 3,354 compute nodes
- 43,048 Intel Xeon processor cores (603 teraflops)
- 64 NVIDIA Tesla M2070 GPUs with 28,672 "streaming GPU" CUDA cores (33 teraflops)
- 480 Intel Phi Many Integrated Core (MIC) co-processors with 28,800 cores (485 teraflops)
- 102.088 terabytes main memory
- InfiniBand interconnect: 20, 40, or 56 gigabits per second

Compute node containing Intel Xeon processors, memory module, and interfaces

Intel Phi Many Integrated Core (MIC) co-processor

Disk Storage and Archive

Shared Storage

- 12.2 petabytes, GPFS-managed
- nobackup/scratch file systems

Mass Storage Archive

SGI Front-End

- Parallel DMF-managed
- SGI Xeon Cluster
- 960-terabyte disk

Oracle/StorageTek Hardware

- 37-petabyte capacity
- T10K tape drives
- SL8500 & 9310 tape libraries

Oracle/ StorageTek silo with 37-petabyte capacity

Monitor and Input

Analysis and Visualization

Data Exploration Theater – Hyperwall

- 17- by 6-foot hyperwall
- 15 46-inch high-definition LCD screens
- 14 million pixels

"Dali" Analysis System

- 272 Intel Xeon cores, 4.3 terabytes memory
- 24 NVIDIA Tesla M2070 GPUs (10,752 "streaming GPU" CUDA cores)

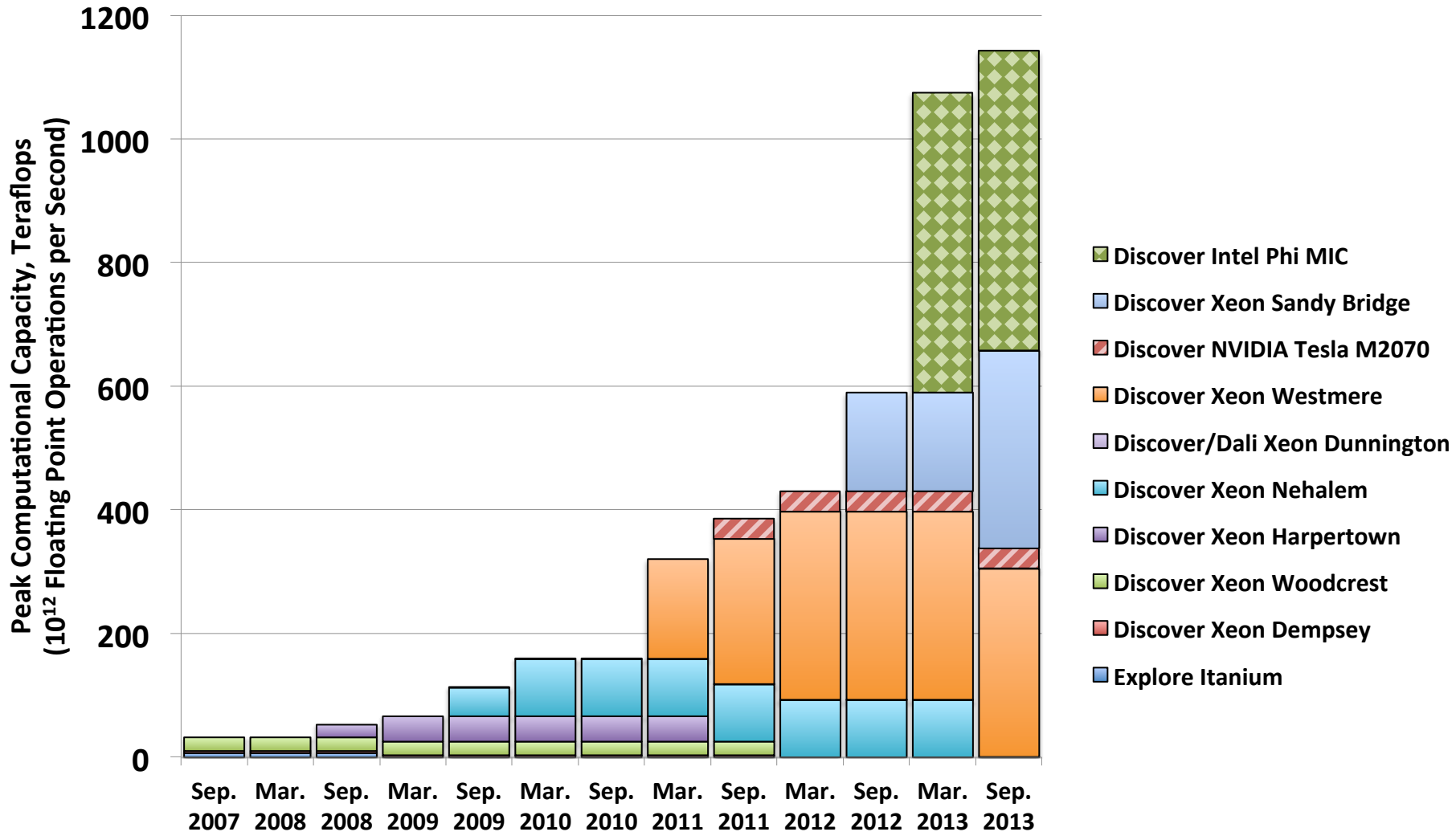
Bill Putman shows global aerosols simulation on NCCS hyperwall

Data Portal

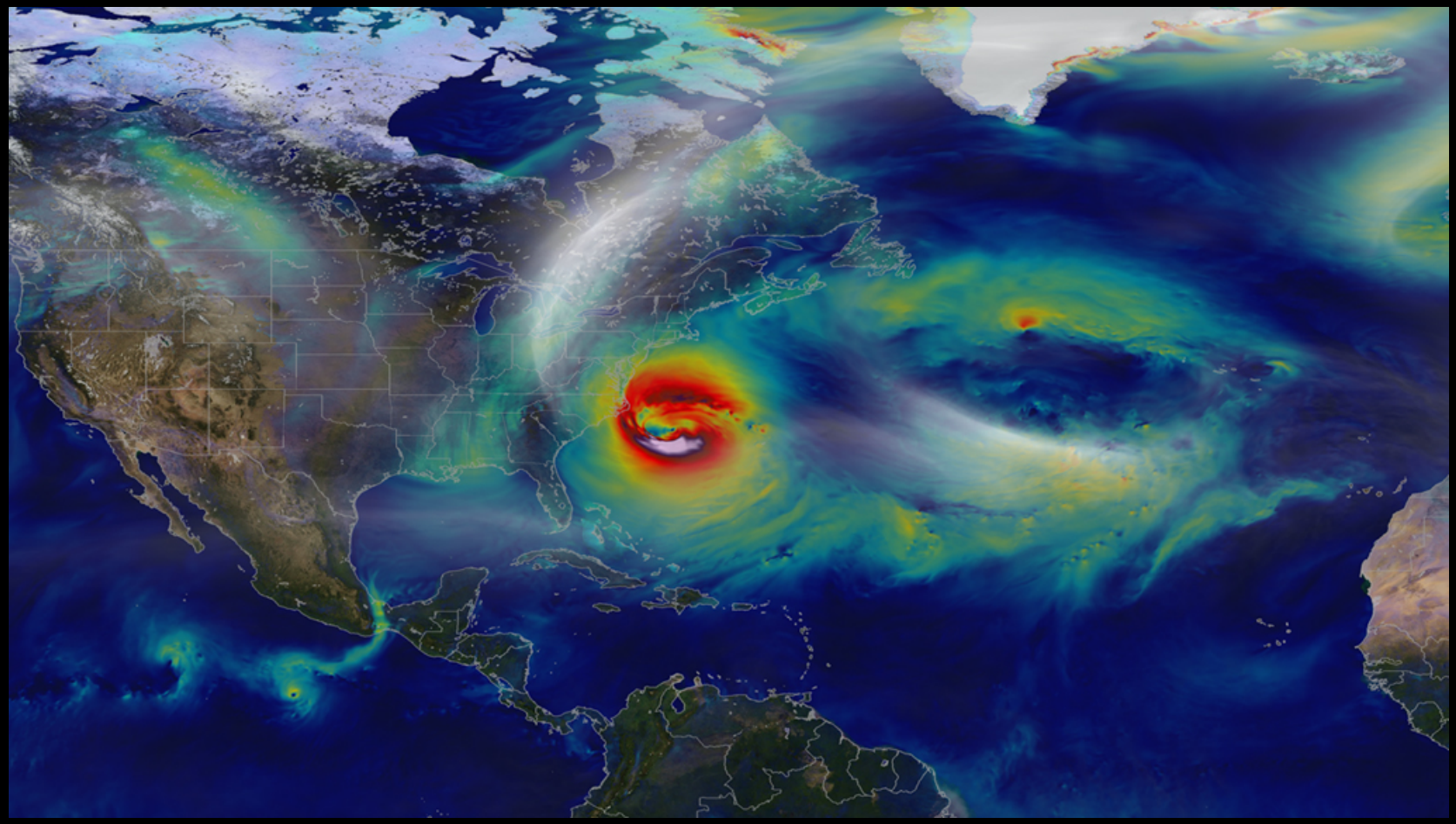
HP Blade Server

- 128 Intel Xeon processor cores, 128 gigabytes memory
- 371-terabyte network disk (GPFS)
- NFS served to compute hosts

NCCS Compute Capacity Evolution September 2007–September 2013

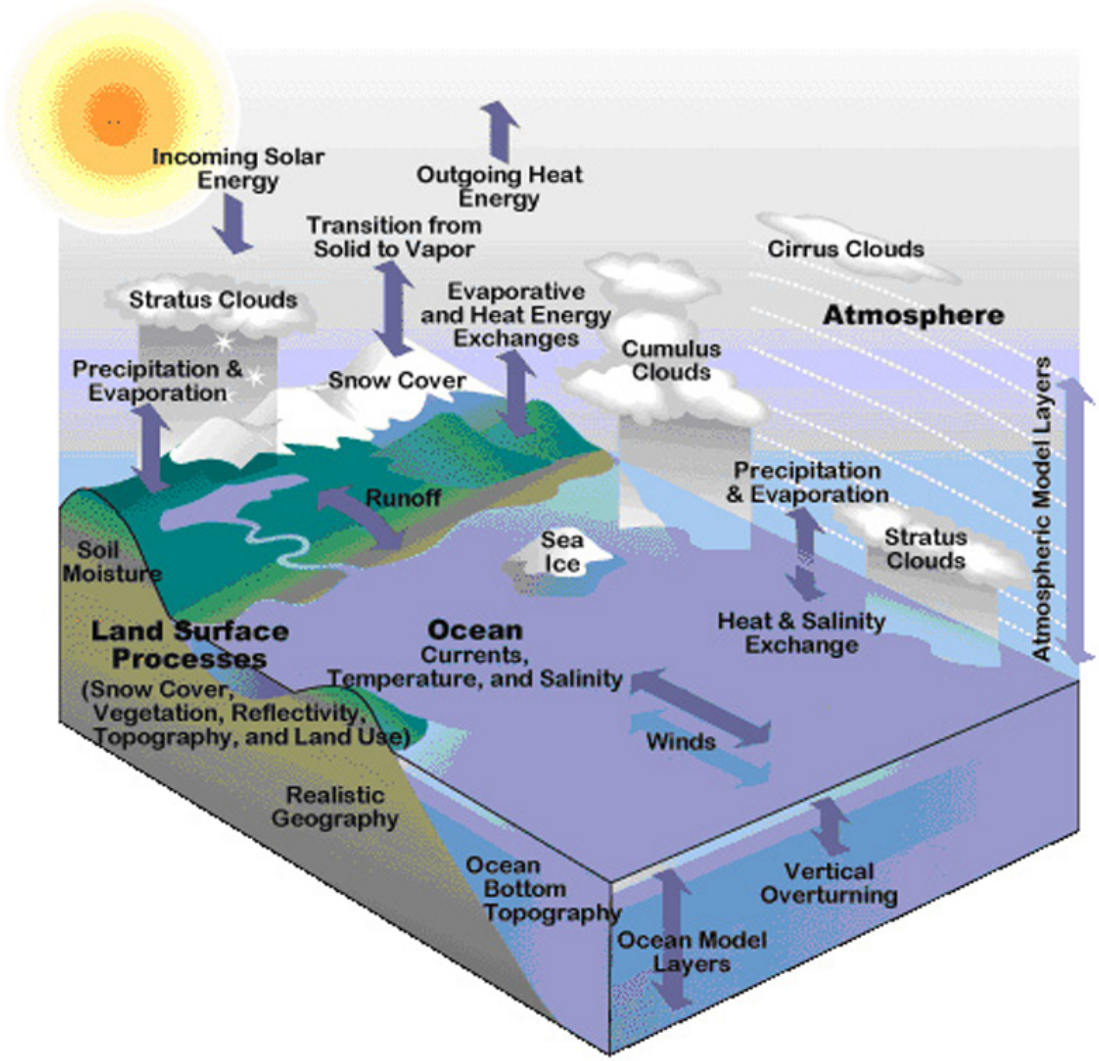


Hurricane Sandy

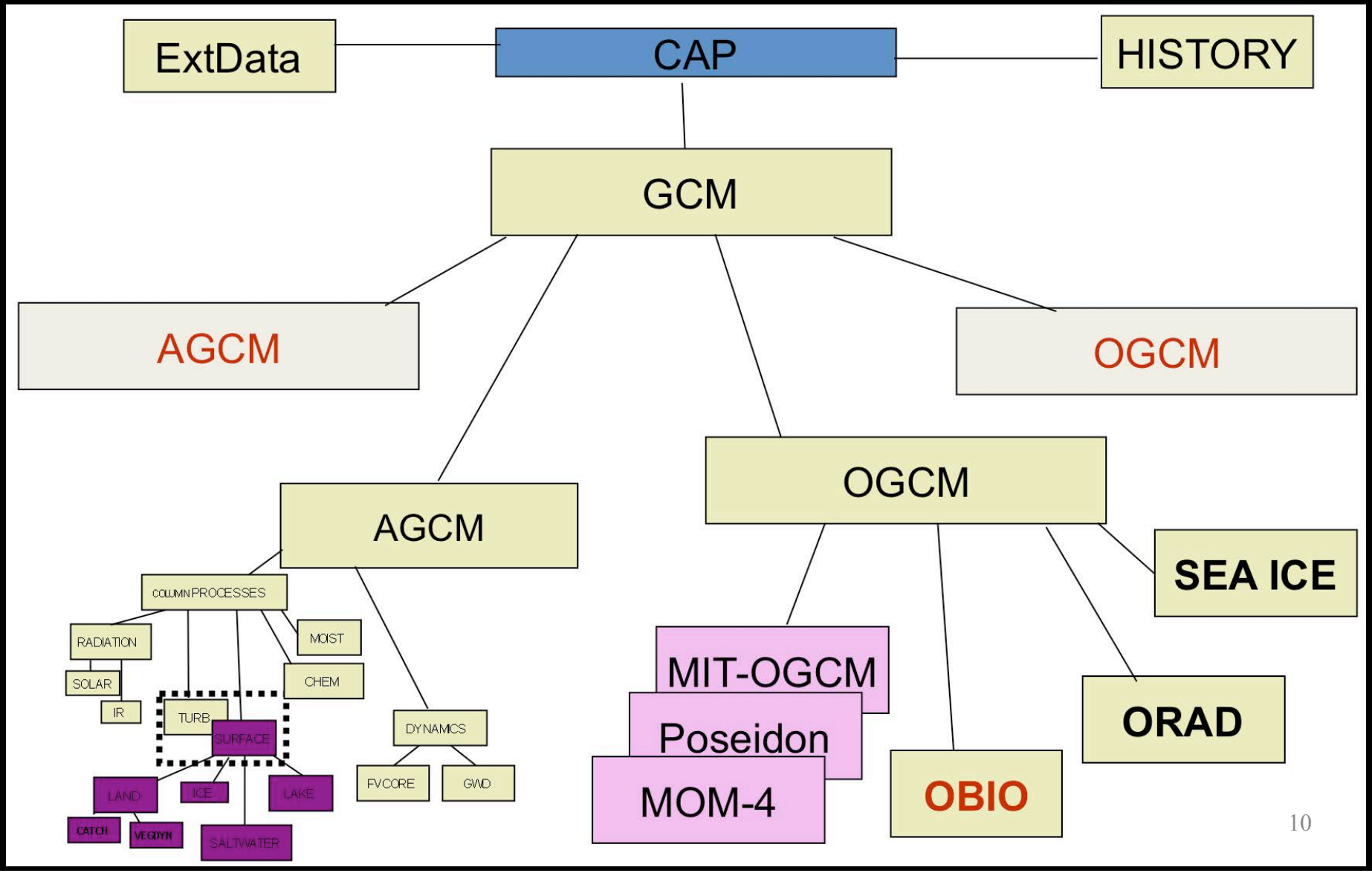


Hurricane Sandy near-surface winds from a 7-kilometer simulation

What Models Simulate



GEOS-5 Model Components



Modeling the Globe

Newton's second law

$$\frac{D_r u}{Dt} - \frac{uv\tan\phi}{r} - 2\Omega\sin\phi v + \frac{c_{pd}\theta}{r\cos\phi}\frac{\partial\Pi}{\partial\lambda} = -\left(\frac{uw}{r} + 2\Omega\cos\phi w\right) + S^u$$

$$\frac{D_r v}{Dt} + \frac{u^2\tan\phi}{r} + 2\Omega\sin\phi u + \frac{c_{pd}\theta}{r}\frac{\partial\Pi}{\partial\phi} = -\left(\frac{vw}{r}\right) + S^v$$

$$\frac{D_r w}{Dt} + c_{pd}\theta\frac{\partial\Pi}{\partial r} + \frac{\partial\Pi}{\partial r} = \left(\frac{u^2+v^2}{r}\right) + 2\Omega\cos\phi u + S^w$$

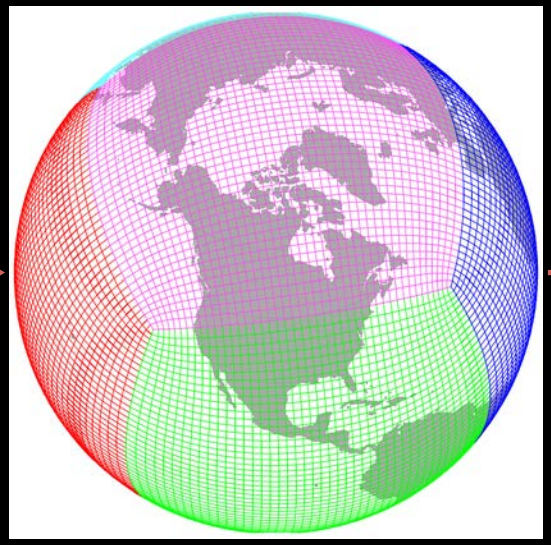
mass continuity

$$\frac{D_r}{Dt}\left(\rho_d r^2\cos\phi\right) + \rho_d r^2\cos\phi\left[\frac{\partial}{\partial\lambda}\left(\frac{u}{r\cos\phi}\right) + \frac{\partial}{\partial\phi}\left(\frac{v}{r}\right) + \frac{\partial w}{\partial r}\right] = 0$$

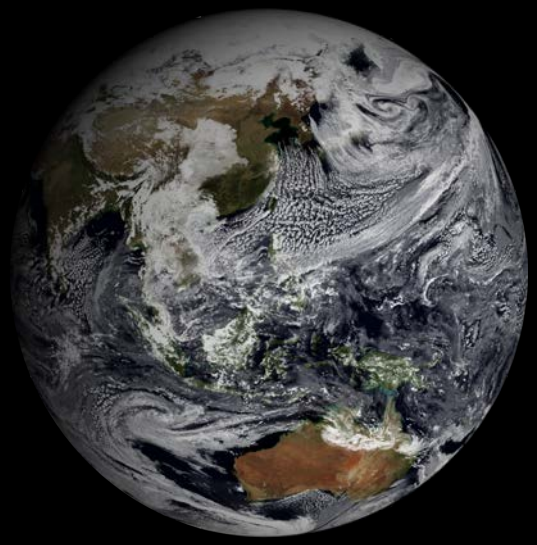
thermodynamics

$$\frac{D_r\theta}{Dt} = S^\theta$$

Navier-Stokes equations

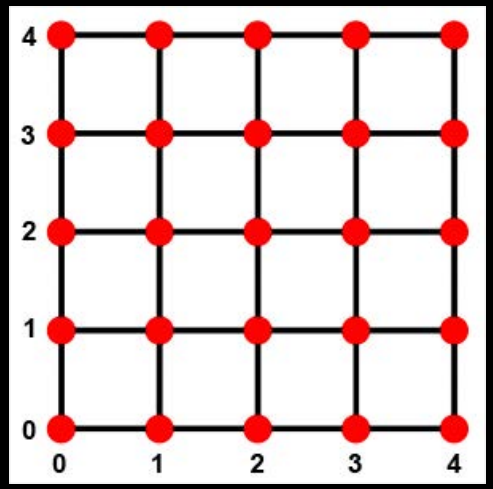


Globe with cube-sphere grid



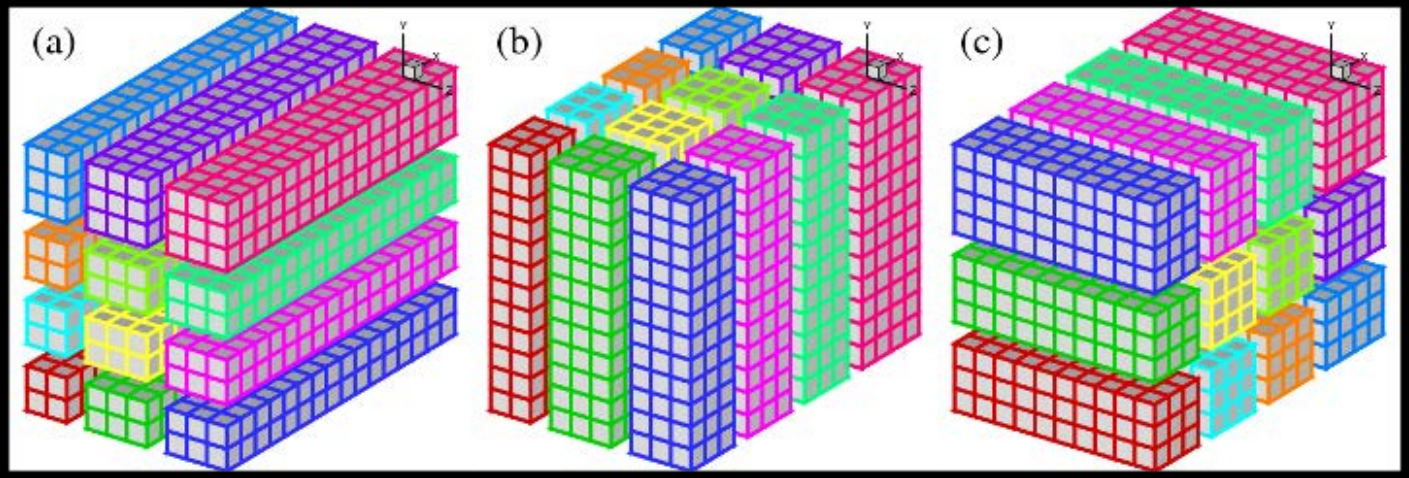
Simulation of global clouds

Modeling Grids



2D grid

Discover supercomputer cabinet



3D grid with domain decomposition

Nature Run

- GEOS-5 atmosphere model
- GEOS-5 coupled to GOCART model for global aerosol studies
- 10-kilometer resolution, fine enough to capture weather events
- Cubed-sphere grid; 6 million grid cells and 72 vertical levels
- Model seeded with sea-surface temperatures and then ran on its own
- Covered May 2005 to April 2007
- Ran on 3,750 processor cores of the Discover supercomputer
- Used more than 3 million core-hours
- Produced over 400 terabytes of data
- Visualizations available at:
  http://svs.gsfc.nasa.gov/goto?30017
  http://svs.gsfc.nasa.gov/goto?3887

Intergovernmental Panel on Climate Change (IPCC)

- IPCC Fifth Assessment Report (AR5)/Coupled Model Intercomparison Project Phase 5 (CMIP5)
- Nearly 30 modeling groups worldwide ran simulations
- NASA contributions from Goddard Institute for Space Studies (GISS) and Global Modeling and Assimilation Office (GMAO)
- GISS ModelE simulations included Representative Constituent Pathways simulations of 2006–2100 and paleoclimate simulations reaching back centuries
- GMAO GEOS-5 ran 10-year forecasts initialized with reanalysis in 1959–2009
- NASA simulations used more than 300 million core-hours to produce more than 60,000 simulation years
- IPCC AR5 Working Group 1 report released September 26, 2013
- Access NASA model visualizations: http://www.nasa.gov/content/goddard/climate-models-show-potential-21st-century-temperature-precipitation-changes/#.UuE9u_30A1

Links

- NASA Center for Climate Simulation
  http://www.nccs.nasa.gov
- NCCS Visualization Wall/Hyperwall Content
  http://www.nccs.nasa.gov/viswall_content.html
- Scientific Visualization Studio
  http://svs.gsfc.nasa.gov
- IPCC AR5/CMIP5:
  https://www.ipcc.ch
  http://cmip-pcmdi.llnl.gov/cmip5/
  http://data.giss.nasa.gov/modelE/ar5/
  http://gmao.gsfc.nasa.gov/research/climate/decadal_pred_GEOS-5/
- Climate Modeling 101
  http://nas-sites.org/climatemodeling/
- Koshland Science Museum Earth Lab—Modeling Interactive
  https://koshland-science-museum.org/explore-the-science/earth-lab/modeling#