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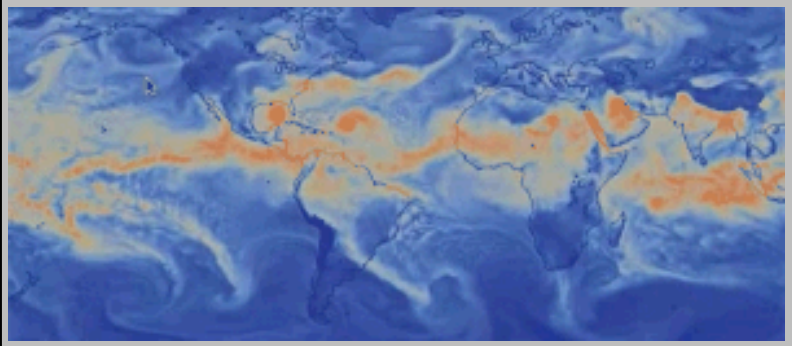

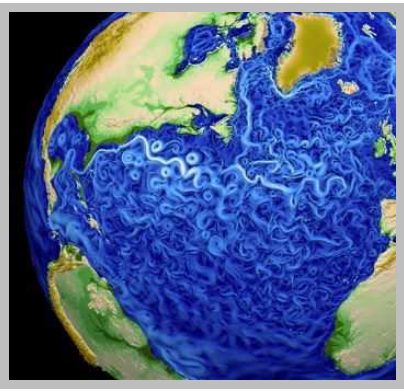

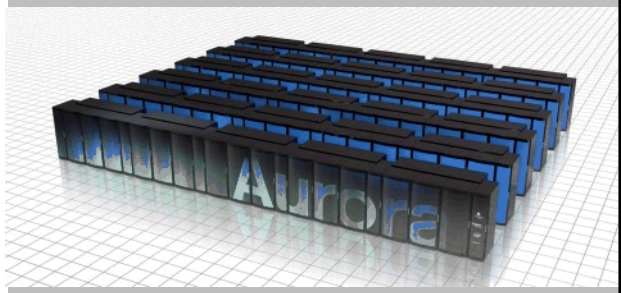

Climate Modeling on Next Generation Computers

Mark Taylor, mataylo@sandia.gov

U.S. DEPARTMENT OF ENERGY

National Nuclear Security Administration

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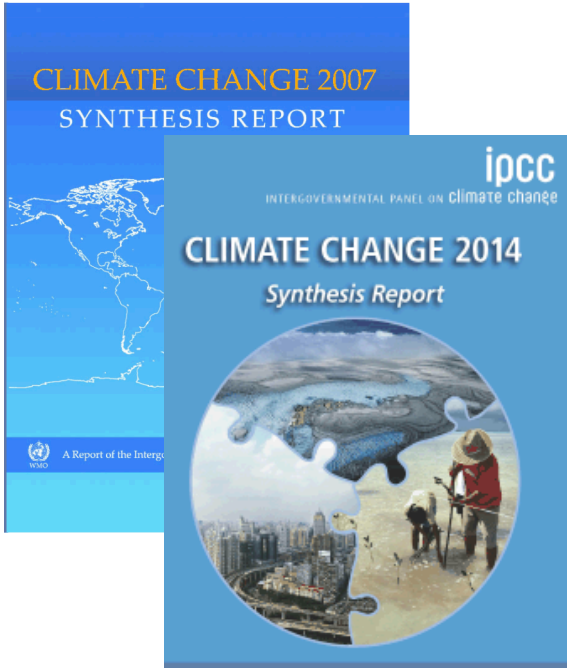
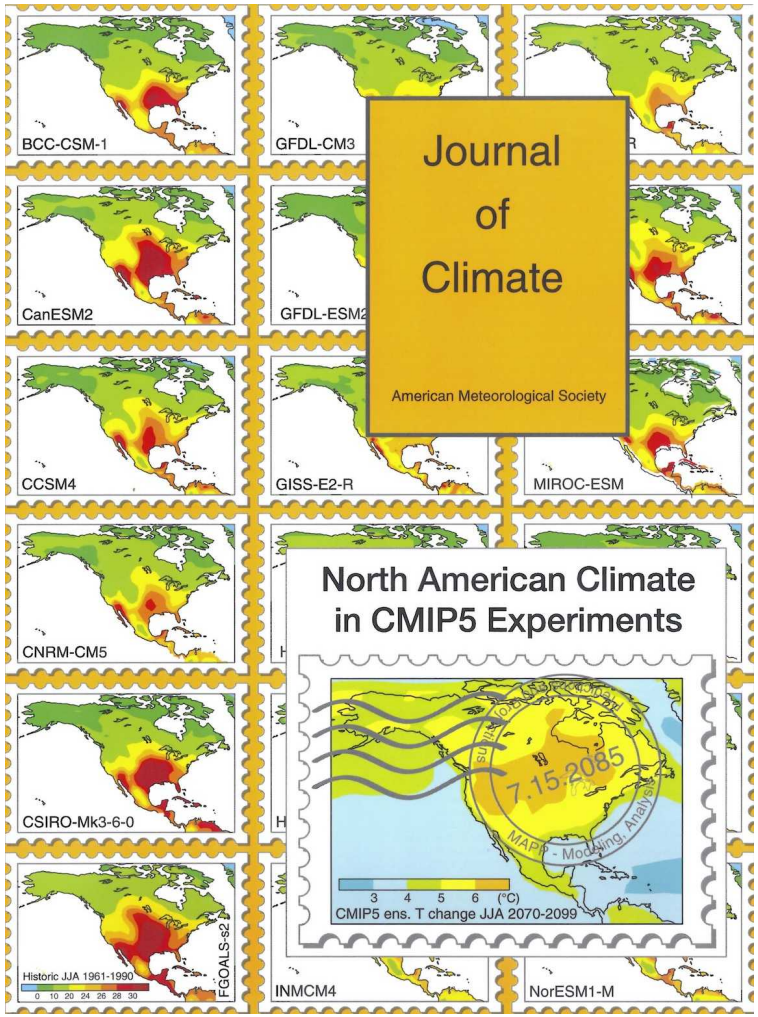
Outline

- International collaboration on climate modeling
- How are climate models used to study climate change?
- Climate modeling and supercomputing

International Collaboration on Climate Modeling

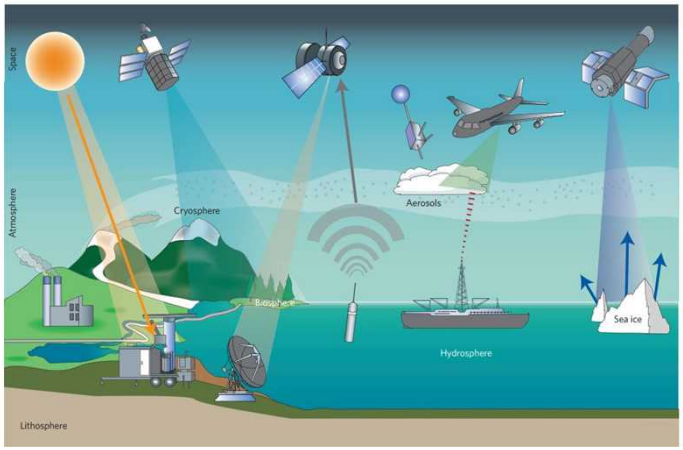


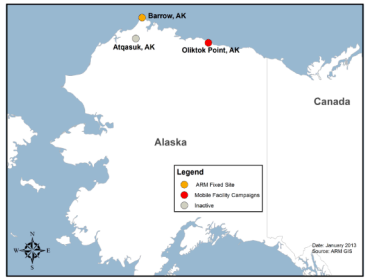


- Examples: The IPCC and the CMIP archive
- Models are one of many factors that contribute to IPCC assessments:
  - Warming is unequivocal
  - Atmospheric GHG concentrations have increased markedly as a result of human activities since 1750
  - Observed warming is very likely due to the observed increase in anthropogenic GHG concentrations.

Observational Data

- Climate modeling community relies heavily on observational data collected and shared internationally
- Satellite, aircraft, ships, land based
- DOE: Atmosphere Radiation Measurement (ARM) program
- Sandia runs the Barrow Alaska ARM site





Influence of 3D solar radiative transfer on a "mock-Walker" circulation, Cole/Canadian Centre for Climate Modelling and Barker/Environment Canada

Indirect Semi-Direct Aerosol Campaign: The Influence of Arctic Aerosol on Clouds, Macdonald (Environment Canada), Strapp/Environment Canada, Korolev/Environment Canada, Gultepe/Environment Canada et al.

Cox CJ, DD Turner, PM Rowe, MD Shupe, and VP Walden. 2014. "**Cloud microphysical properties retrieved from downwelling infrared radiance measurements made at Eureka, Nunavut, Canada** (2006-09)." *Journal of Applied Meteorology and Climatology*, 53(3), doi:10.1175/JAMC-D-13-0113.1.

Cox CJ, VP Walden, and PM Rowe. 2012. "**A comparison of the atmospheric conditions at Eureka, Canada, and Barrow, Alaska (2006-2008).**" *Journal of Geophysical Research – Atmospheres*, 117, D12204, doi:10.1029/2011JD017164.

Trishchenko AP and A Jevtic. 2004. **Analysis of radiation budget datasets derived from satellite, modeling and ground observations over Canada**. Presented at International Radiation Symposium 2004 IRS. Busan, Korea. ARM

Earth's global mean energy balance

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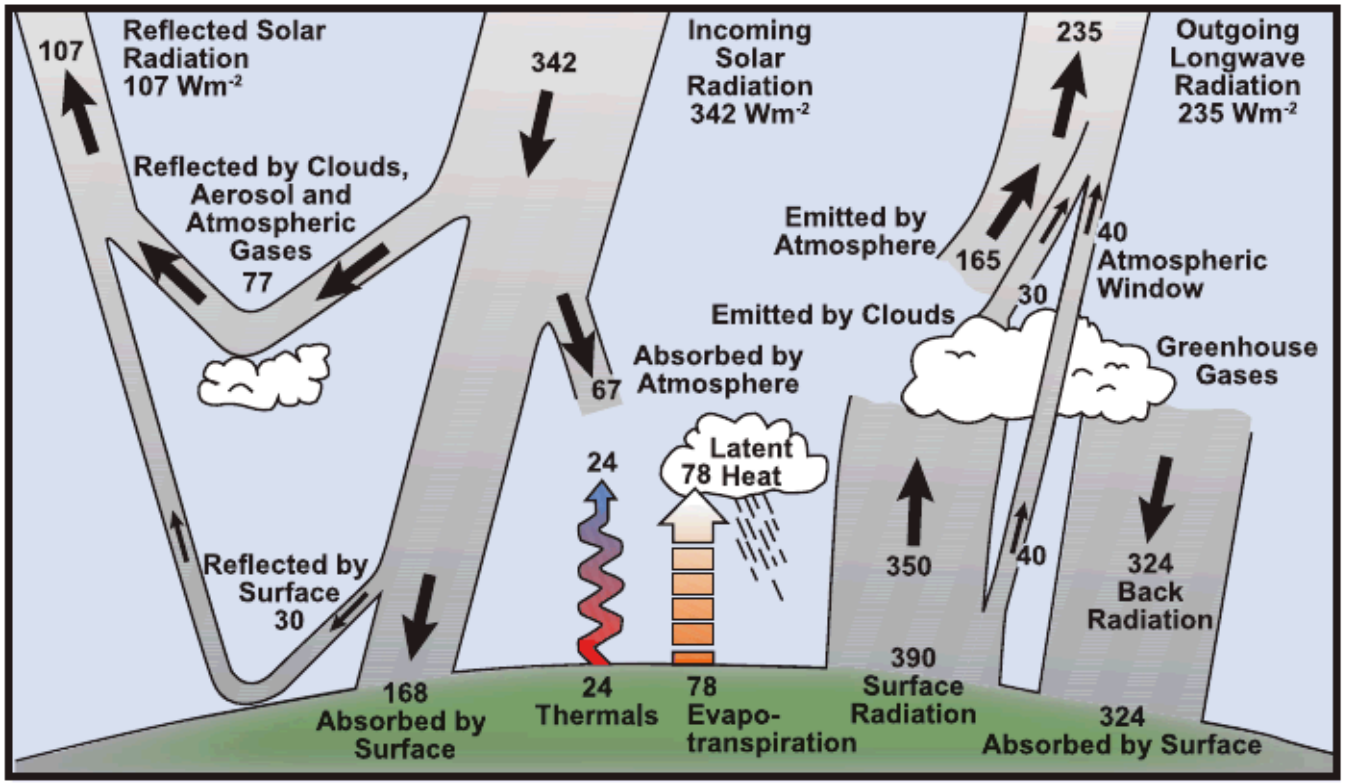
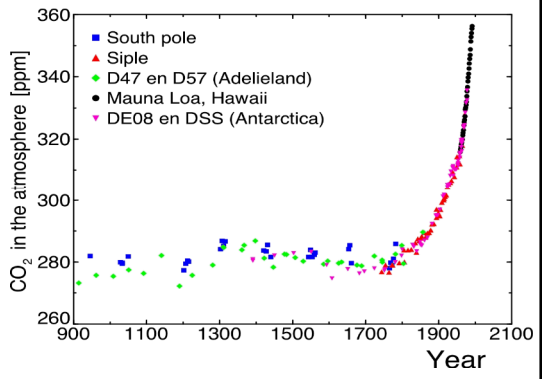
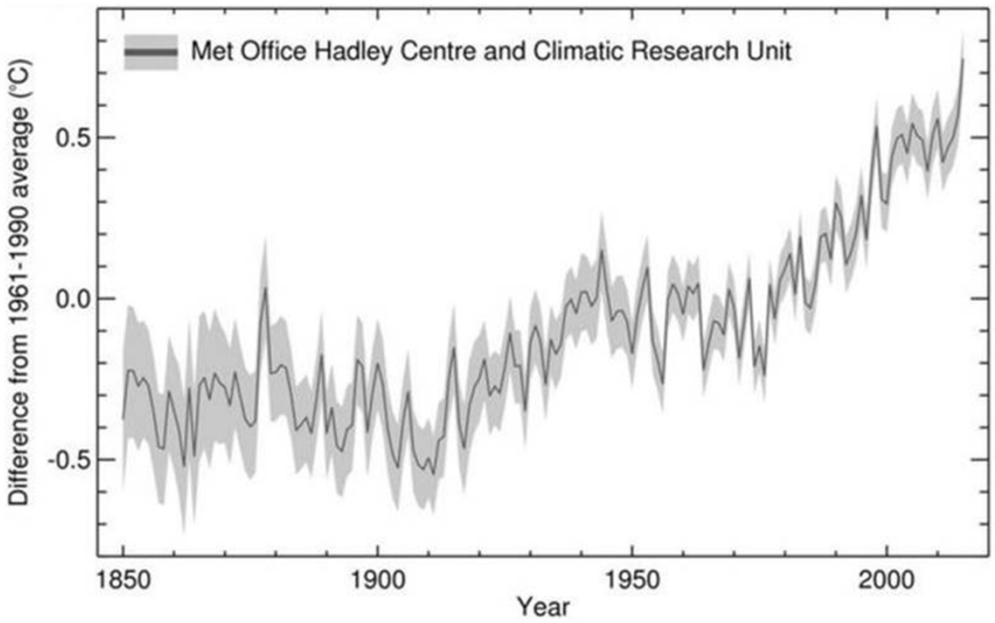


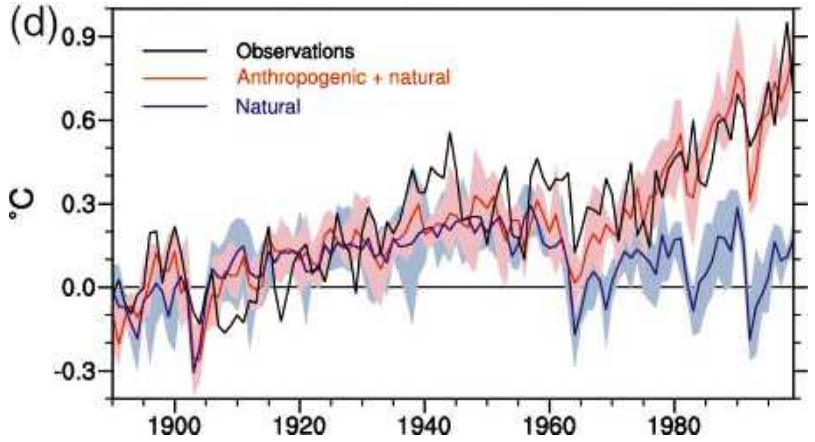


FAQ 1.1, Figure 1. *Estimate of the Earth's annual and global mean energy balance. Over the long term, the amount of incoming solar radiation absorbed by the Earth and atmosphere is balanced by the Earth and atmosphere releasing the same amount of outgoing longwave radiation. About half of the incoming solar radiation is absorbed by the Earth's surface. This energy is transferred to the atmosphere by warming the air in contact with the surface (thermals), by evapotranspiration and by longwave radiation that is absorbed by clouds and greenhouse gases. The atmosphere in turn radiates longwave energy back to Earth as well as out to space. Source: Kiehl and Trenberth (1997).*

Source: IPPC 4th Assessment Report

Global Mean Temperature Anomaly





Source: Meehl et al., J. Climate 17, 2004

Accelerated Climate Model for Energy (ACME)

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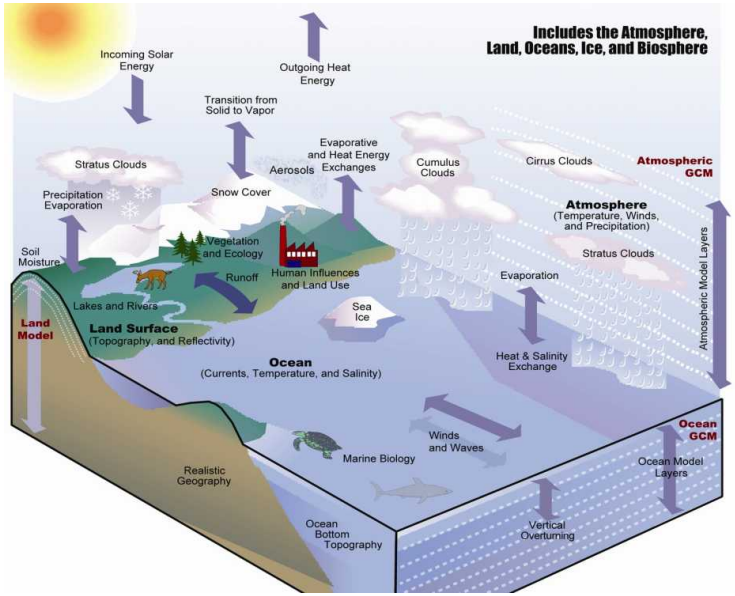
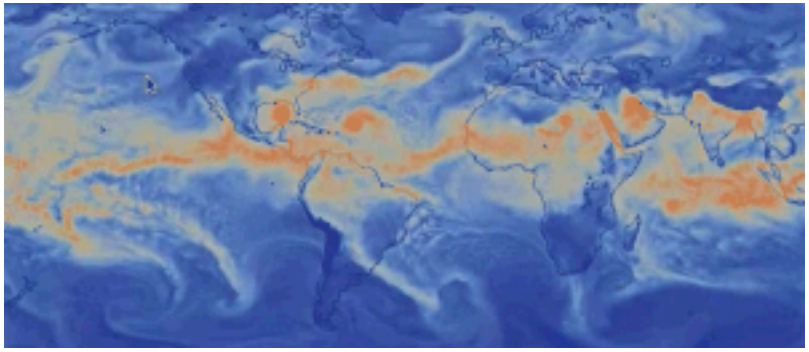
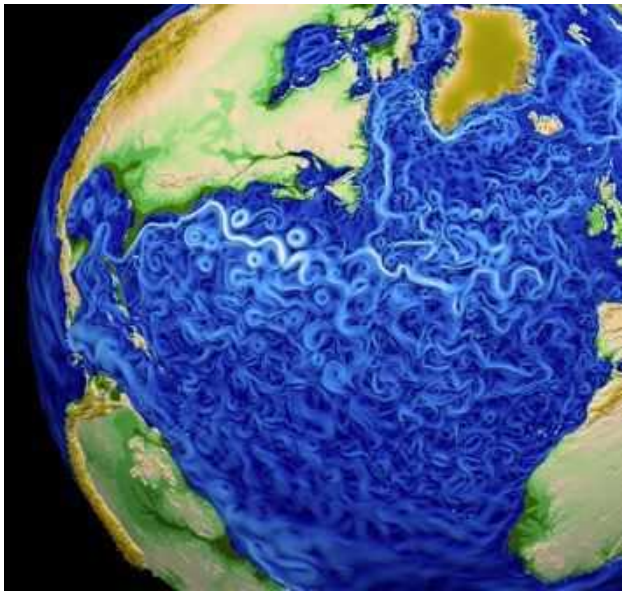
- A DOE Earth System Model for DOE problems running on DOE computers
- 8 DOE labs, NCAR, Kitware and universities. Total ~45 FTEs spread over 100 staff
- Atmosphere, Land, Ocean and Ice component models
- Development driven by DOE-SC mission interests: Energy/water issues looking out 40 years
- Particular focus on ensuring ACME will run well on next generation DOE leadership computing facilities
- ACME is open source with public release of code & simulations



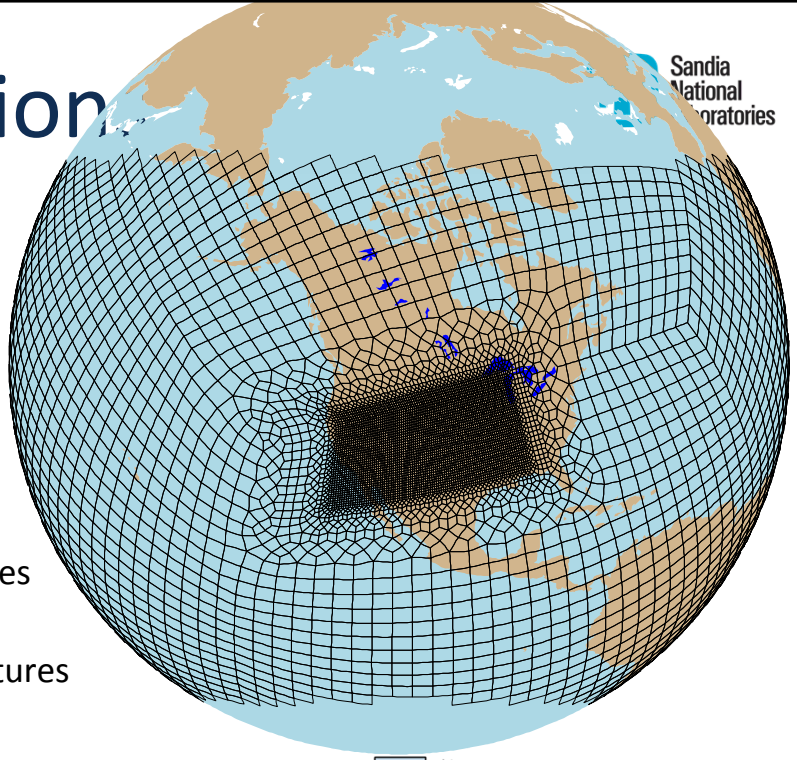




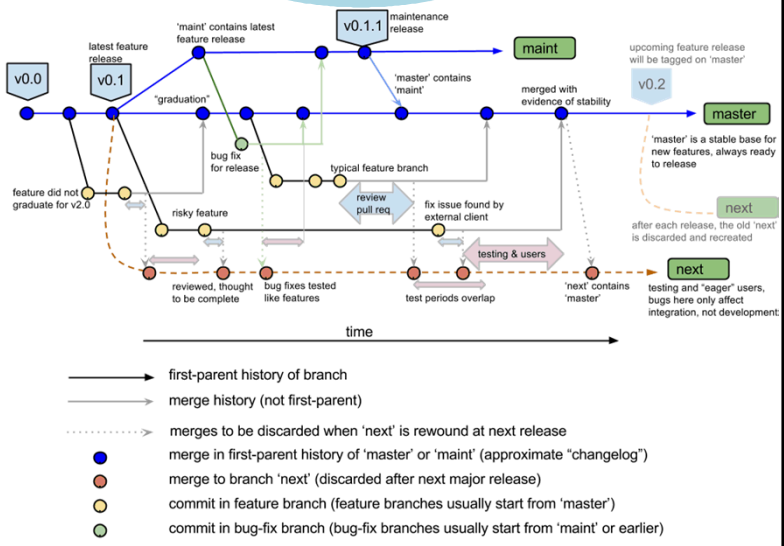
Climate Science Drivers

- *Water cycle:*
  - What are the processes and factors governing precipitation and the water cycle today and how will precipitation evolve over the next 40 years?
- *Biogeochemistry:*
  - What are the contributions and feedbacks from natural and managed systems to current greenhouse gas fluxes, and how will those factors and associated fluxes evolve in the future?
- *Cryosphere:*
  - What will be the long-term, committed Antarctic Ice Sheet contribution to sea level rise (SLR) from climate change during 1970–2050?

ACME - Sandia contribution



- Climate Codes:
  - atmosphere dynamics (HOMME)
  - ice sheet dynamics (Albany/FELIX)
- Numerical Methods:
  - full support for unstructured meshes
  - highly scalable algorithms for next generation architectures (Trilinos)
  - high-order methods tailored for next generation architectures
  - Extensive UQ tools and practice (Dakota)
- Software engineering:
  - Best practices: agile development with continuous integration
  - Object oriented development for performance portability
- National Leadership:
  - ACME project Chief Computational Scientist (Mark Taylor)
  - ACME project Software Engineering Group Lead (Andy Salinger)
  - Lead author of DOE-wide Climate modeling white paper for Exascale Computing initiative



Horizontal Grid Resolution

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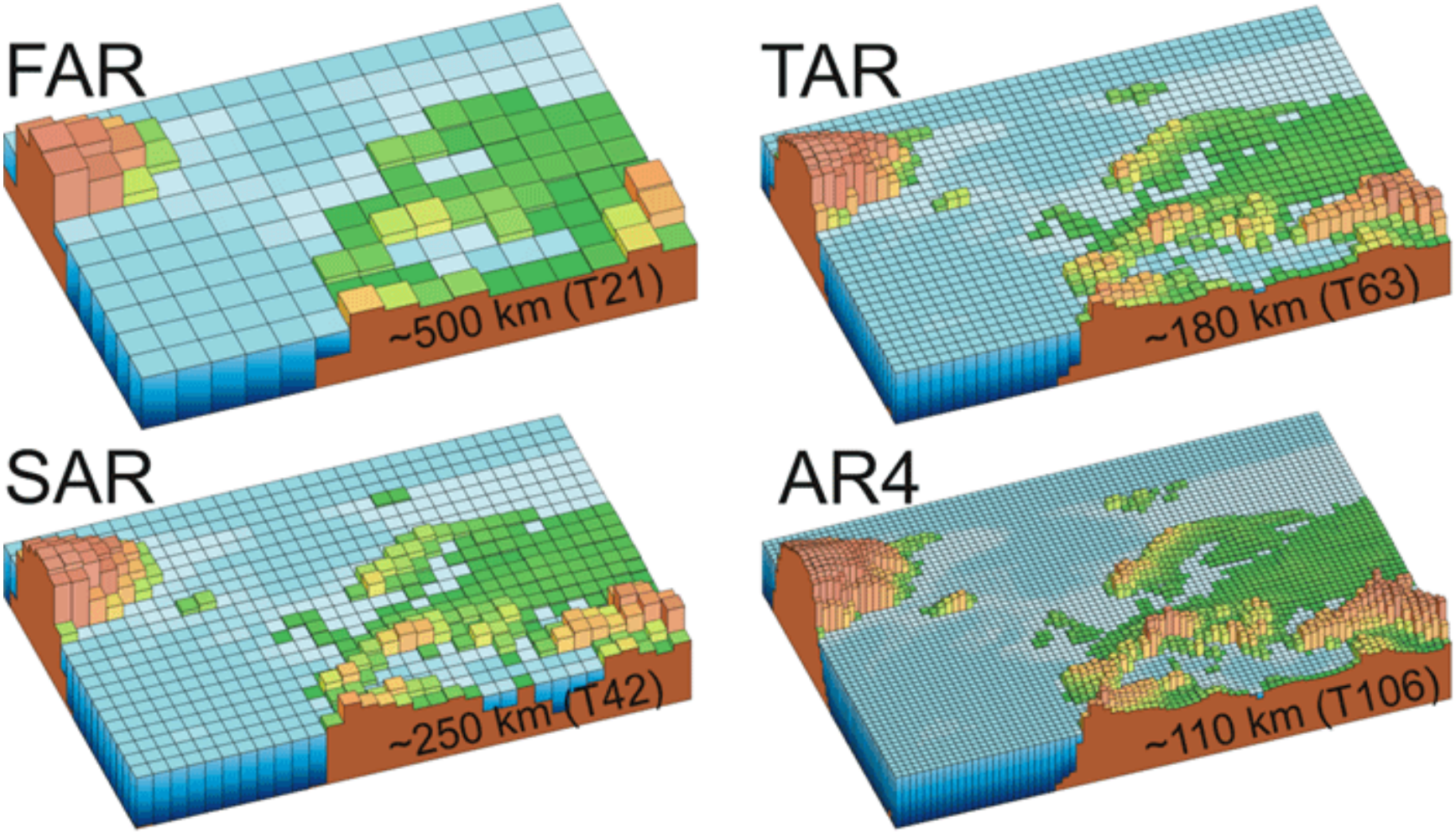

Source: IPCC 4th Assessment Report, 2007

Resolving Tropical Cyclones at High Resolution

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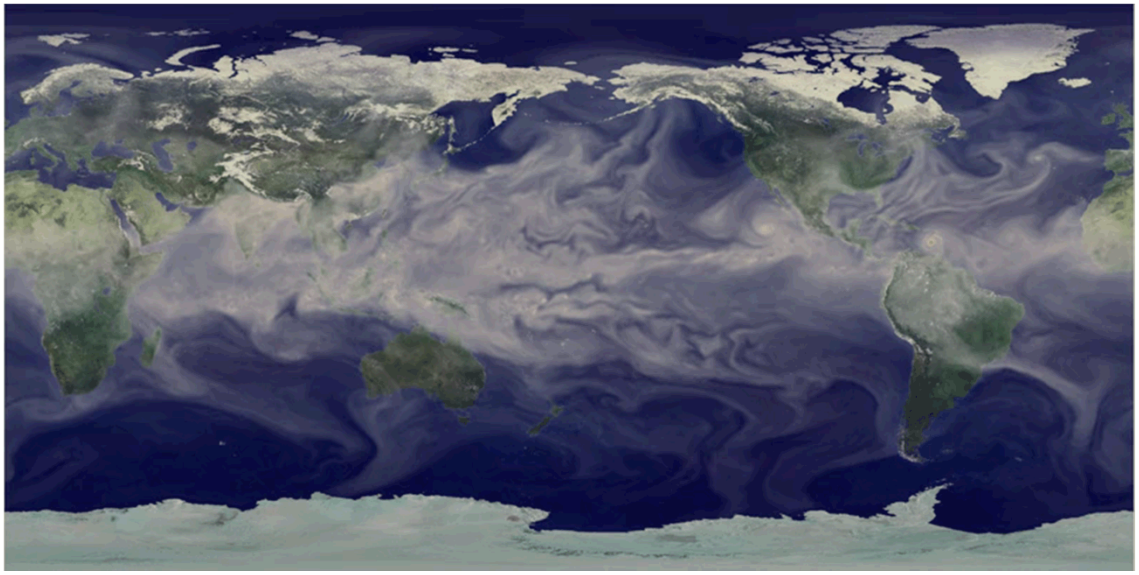
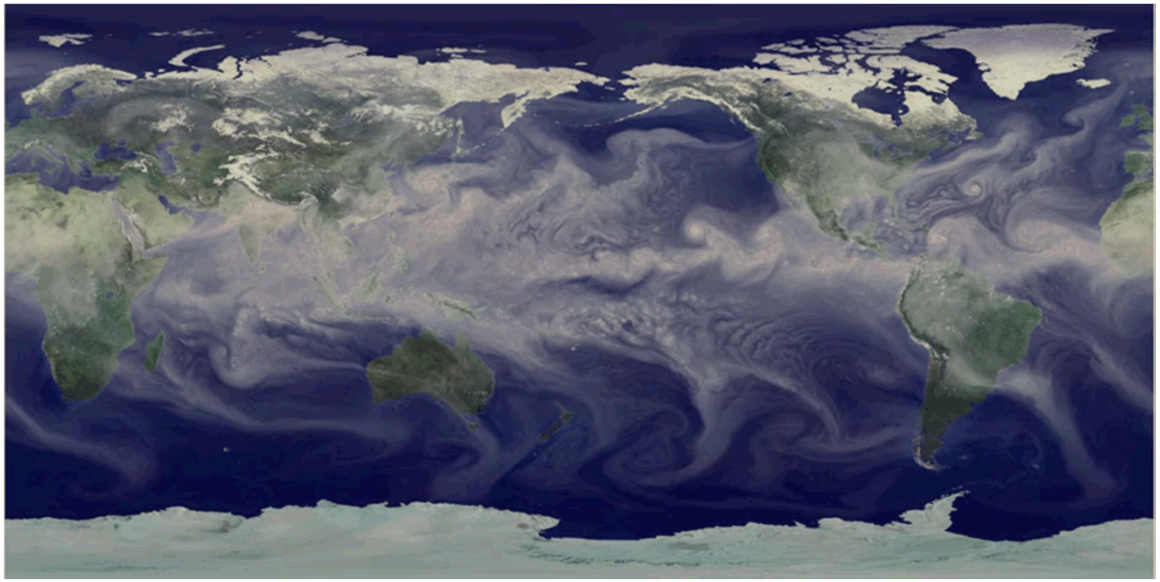
25km



13km



20 day loop, September conditions, showing vertically totaled atmosphere water content

High resolution is required in order for the model to simulated tropical cyclones

At 100km resolution, there is almost no cyclone activity

ACME at 25km does a reasonable job at capturing tropical cyclones, including category 5 storms

At 13km, which is a typical resolution of global weather forecast models, simulated tropical cyclones become more realistic.

A DOE model for DOE problems running on **DOE computers**

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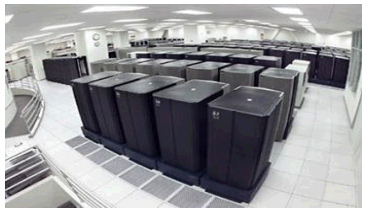
- Transition to new architectures will be disruptive
  - Perhaps even more disruptive than the transition from vector to parallel supercomputers in the 2000's
- By 2018, >95% of the computing power in DOE will be on multicore (Intel Phi) or NVIDIA GPU systems
  - Driven mostly by power considerations
- If we do nothing, today's climate models will run *slower* on these systems than they run on today's systems
  - As with the transition from vector to MPP: it may take ~5 years before either of these new architectures can outperform conventional systems on climate applications

Earth Simulator, 2002



BG/L 2008

ACME on today's systems

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- NERSC Edison
  - 5600 Nodes,
  - 24 cores (dual Intel Ivey Bridge)
  - Watercycle Prototype: 3.1 SYPD
- OLCF Titan
  - 19K Nodes.
  - 16 core AMD Opteron + NVIDIA GPU
  - Watercycle Prototype: 2.2 SYPD
- ALCF Mira
  - 49K Nodes
  - 16 core PowerPC
  - Watercycle Prototype: 0.9 SYPD
  - Need better scaling, or can run effectively via ensembles
- All ACME v1 simulations will have to be done on these machines!

ACME Next Generation Machines

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- Key goal of ACME: Run on next generation DOE machines:
- NERSC Cori (late 2016)
  - 9300 Nodes
  - Intel Phi KNL, 72 cores x 4 threads
- OLCF Summit 2018
  - 3400 Nodes
  - Multiple IBM power9 and NVIDIA GPUs
- ALCF Aurora 2018
  - 50K Nodes, 3rd gen Intel Phi