Scientific Grand Challenges Workshop Series:

Challenges in Climate Change Science and the Role of Computing at the Extreme Scale

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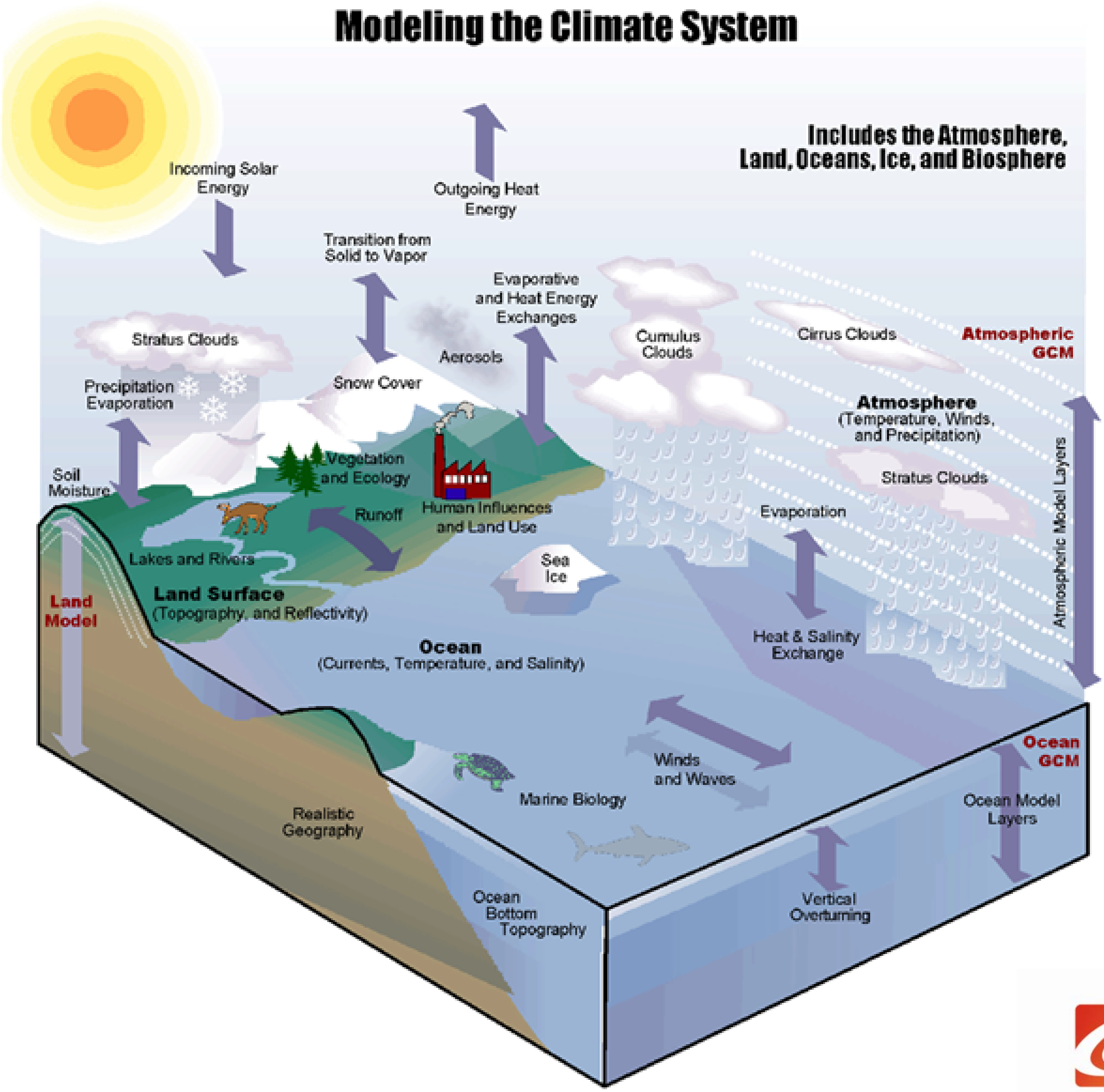
Our challenge is to model this complex system



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Workshop Goals

- Review and identify the critical scientific challenges.
- Prioritize the challenges in terms of decadal or annual timelines.
- Identify the challenges where computing at the extreme scale is critical for climate change science success within the next two decades.
- Engage international scientific leaders in discussing opportunities to shape the nature of extreme scale scientific computing.
- Provide the high performance computing community with an opportunity to understand the potential future needs of the climate change research community.
- Look for breakthroughs.

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Workshop Format

- The 95 workshop attendees represented the following groups:
  - academia (18 participants)
  - national laboratories (34)
  - federal agencies (31)
  - research institutions (12)
  - 11% were international participants
- The leads of the breakout sessions prepared a white paper in advance of the workshop to focus the discussion.
- Plenary sessions framed the workshops, but most of the meeting took place in the following breakout panels:
  - **Model Development and Integrated Assessment**

    Leads: David Bader Lawrence Berkeley National Laboratory

    Bill Collins, Lawrence Livermore National Laboratory
  - **Algorithms and Computational Environment**

    Leads: John Drake, Oak Ridge National Laboratory

    Mark Taylor, Sandia National Laboratory
  - **Data, Visualization and Productivity**

    Leads: Dean Williams, Lawrence Livermore National Laboratory

    Don Middleton, National Center for Atmospheric Research
  - **Decadal Predictability and Prediction**

    Lead: Ben Kirtman, University of Miami

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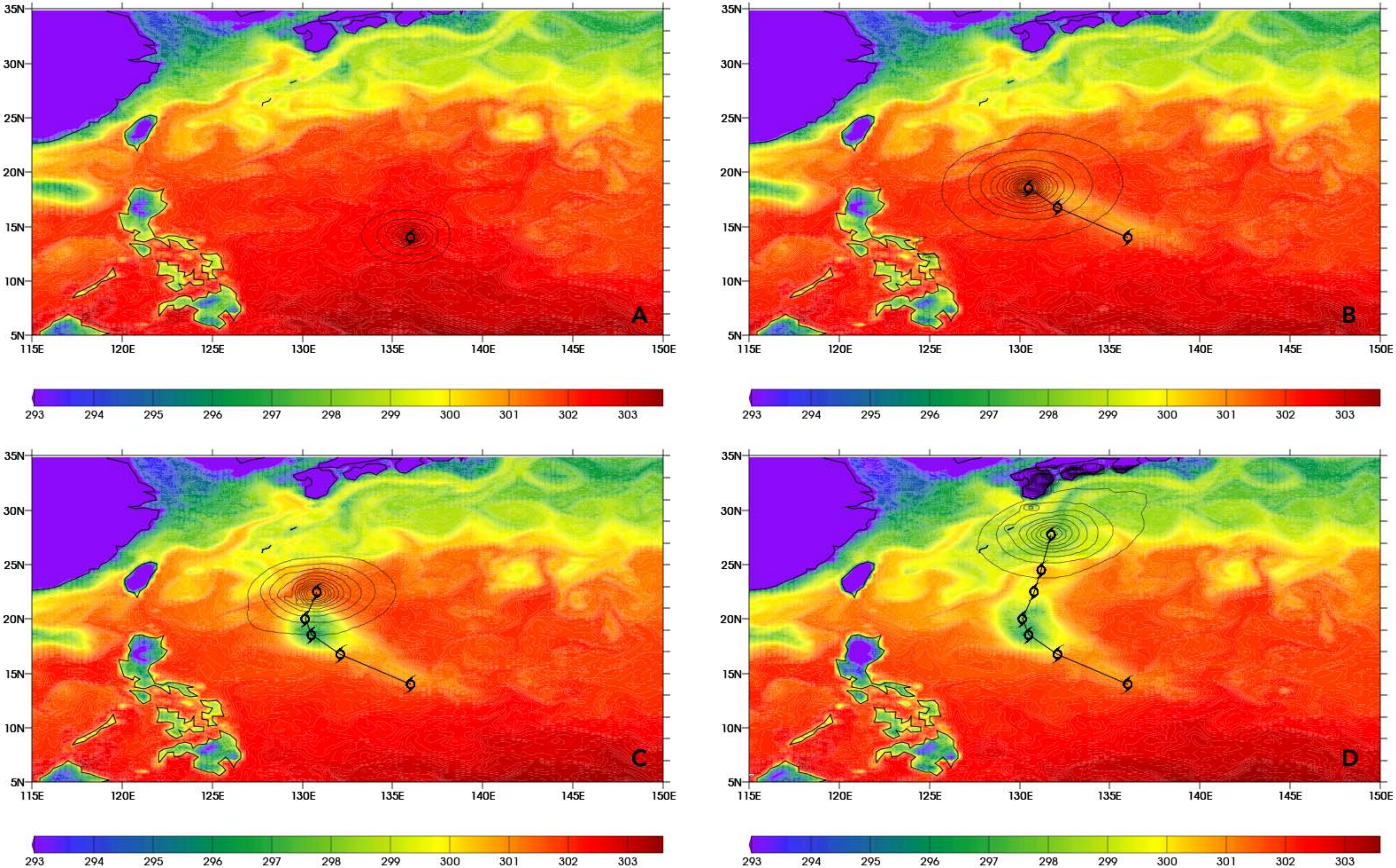
We are working on global models to capture small-scale features such as hurricanes and simulate how they interact with oceans



Previous Reports

We considered the following reports as foundational information for this workshop:

- *Identifying Outstanding Grand Challenges in Climate Change Research: Guiding DOE's Strategic Planning,* for the Office of Biological & Environmental Research, U.S. Department of Energy
- *Report on Computational and Information Technology Rate Limiters to the Advancement of Climate Change Science,* for the Office of Advanced Scientific Computing Research , U.S. Department of Energy.

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Priority Research Directions were established for each of the Breakout sessions

Some PRDs are highlighted as follows:

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PRDs for Model Development and Integrated Assessment

- How do the carbon, methane, and nitrogen cycles interact with climate change?
- **How will local and regional water, ice, and clouds change with global warming?**
- How will the distribution of weather events, particularly extreme events, that determine regional climate change with global warming?
- **What are the future sea level and ocean circulation changes**?

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How will local and regional water, ice, and clouds change with global warming?

To answer this question:

- Determine critical cloud controls on climate
- Determine importance of motions and particle-scale processes that are still unresolved
- Develop and apply global cloud-resolving models
    - ✓ These models will bridge scales from weather to climate for the first time.
    - ✓ These models will ultimately improve our ability to project changes in regional water cycles, a critical element of integrated assessment (Timescale: 5-10 years)
    - ✓ Cloud-resolving models will be used to improve traditional climate models used for climate projection. (Timescale: 2-5 years)

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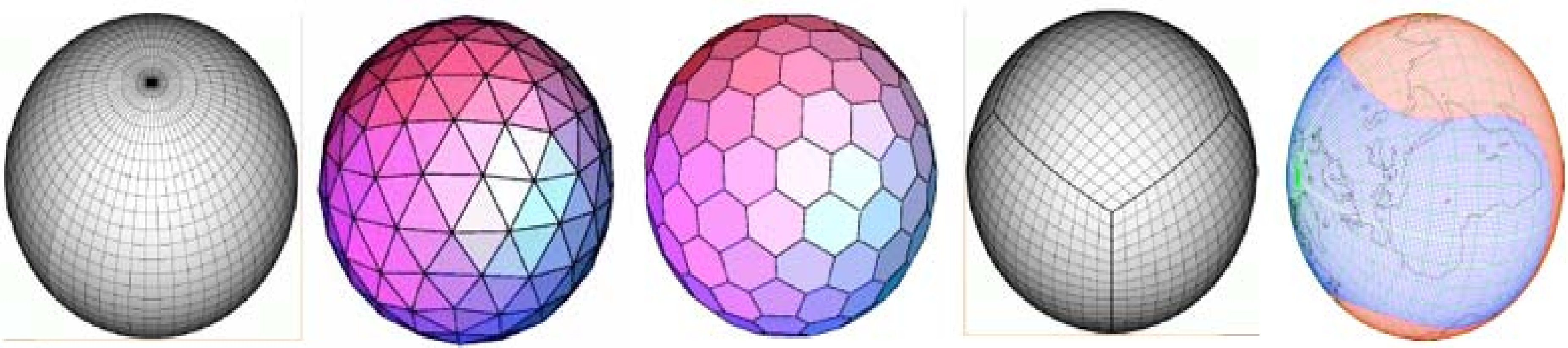
What are the future sea level and ocean circulation changes?

- Describe the importance processes governing ice sheet melt
- More accurately represent important vertical mixing in the ocean
- Determine how mixing eddies and surface forcing combine to affect the stability and variability of the meridional overturning circulation.

PRDs for Algorithms and Computational Environment

- Develop numerical algorithms to efficiently use upcoming petascale and exascale architectures
- Form international consortium for parallel input/output, metadata, analysis, and modeling tools for regional and decadal multimodel ensembles
- Develop multicore and deep memory languages to support parallel software infrastructure
- Train scientists in the use of high-performance computers.

Exploring different grid systems to efficiently use petascale and exascale architectures will help develop modeling effectiveness



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PRDs for Decadal Predictability and Prediction

- Identify sources and mechanisms for potential decadal predictability
- Develop strategies for tapping into this predictability and ultimately realizing predictions that have societal benefit

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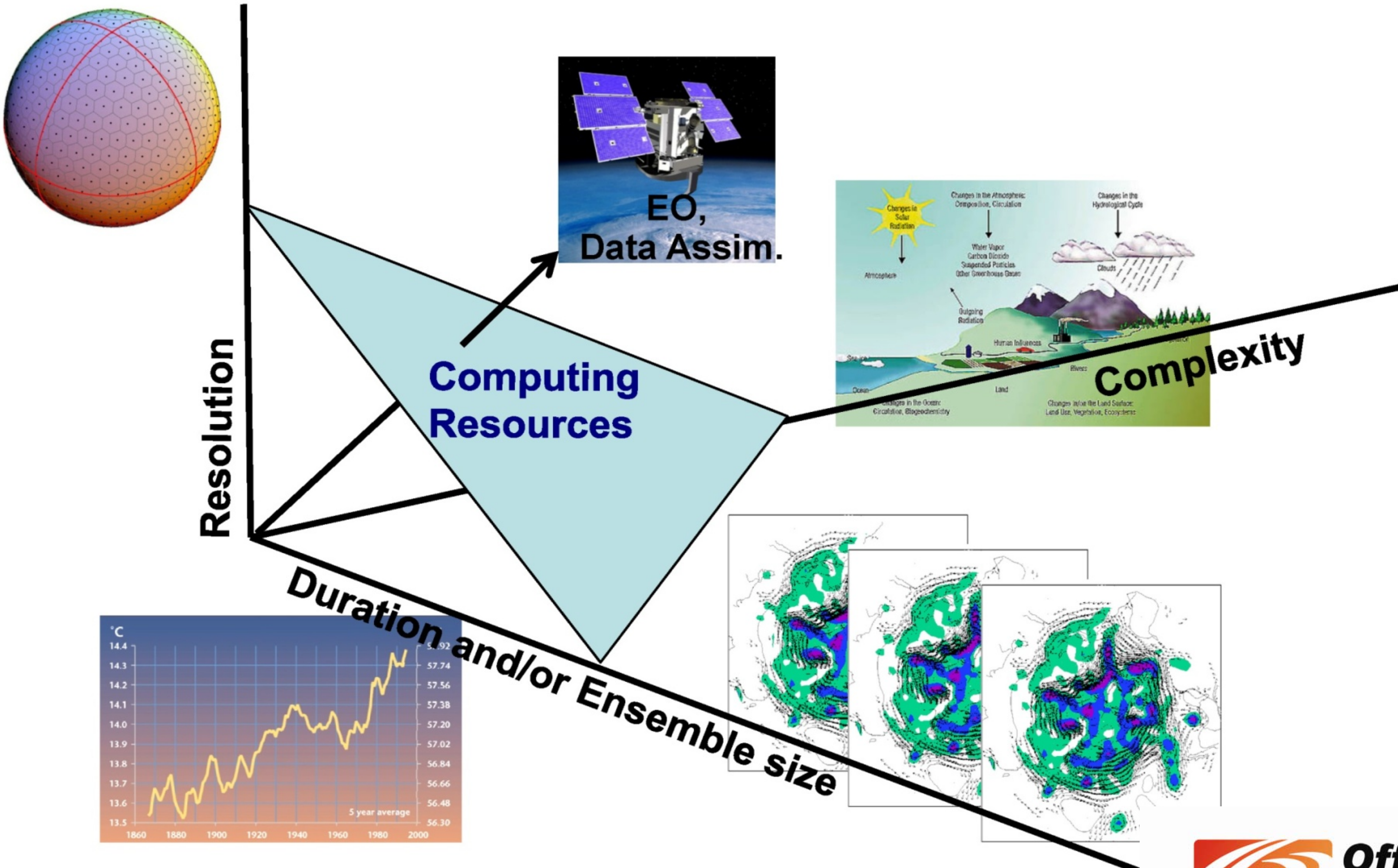
Substantial computing resources are required for decadal climate prediction



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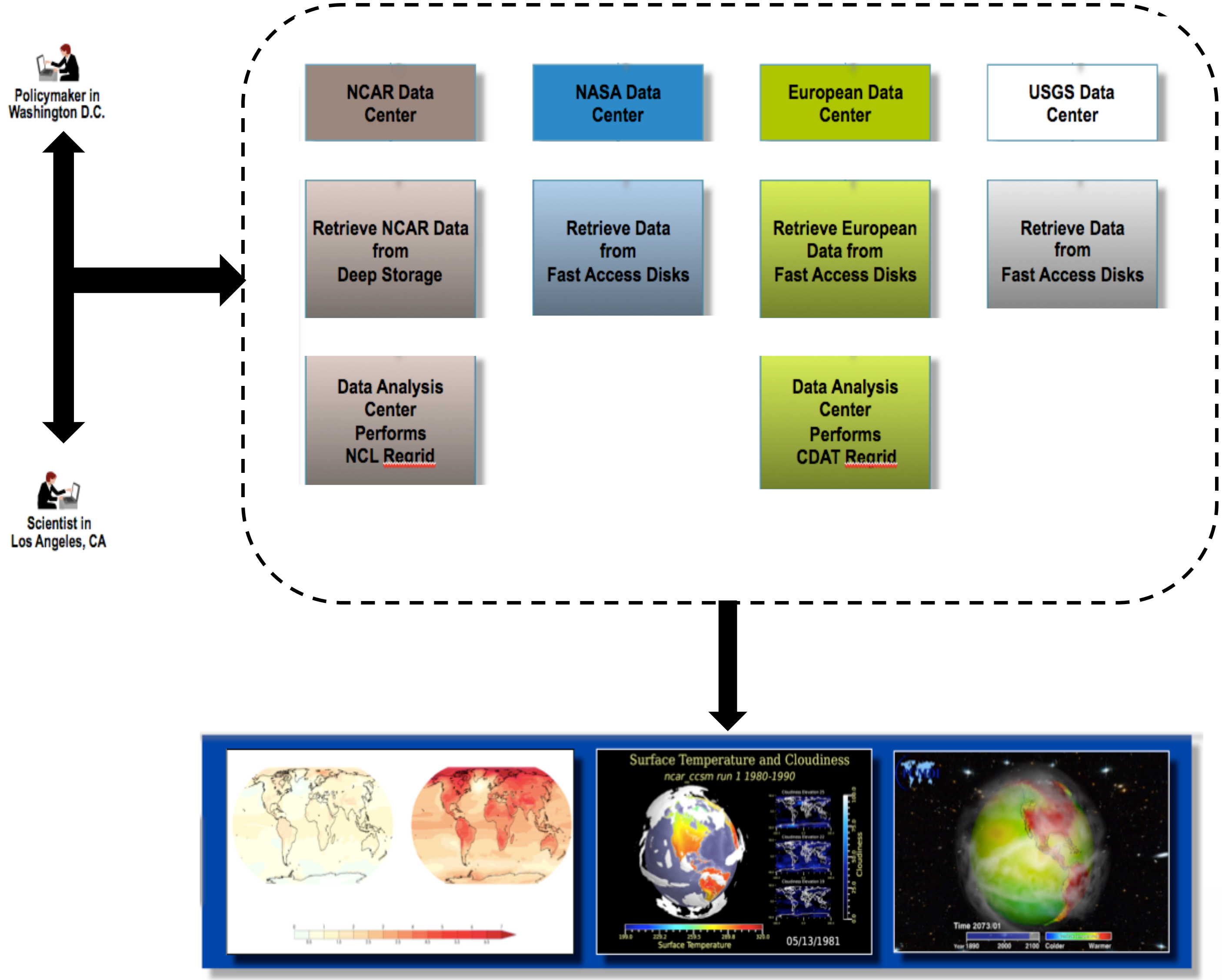
PRDs for Data Visualization and Computing Productivity

- Develop new, robust techniques for dealing with the input/output, storage, processing, and wide-area transport demands of exascale data
- Integrate diverse and complex data
- Dedicate resources to the development of standards, conventions, and policies, and contribute to related committees

Diverse and complex data are integrated into visualizations to communicate model predictions



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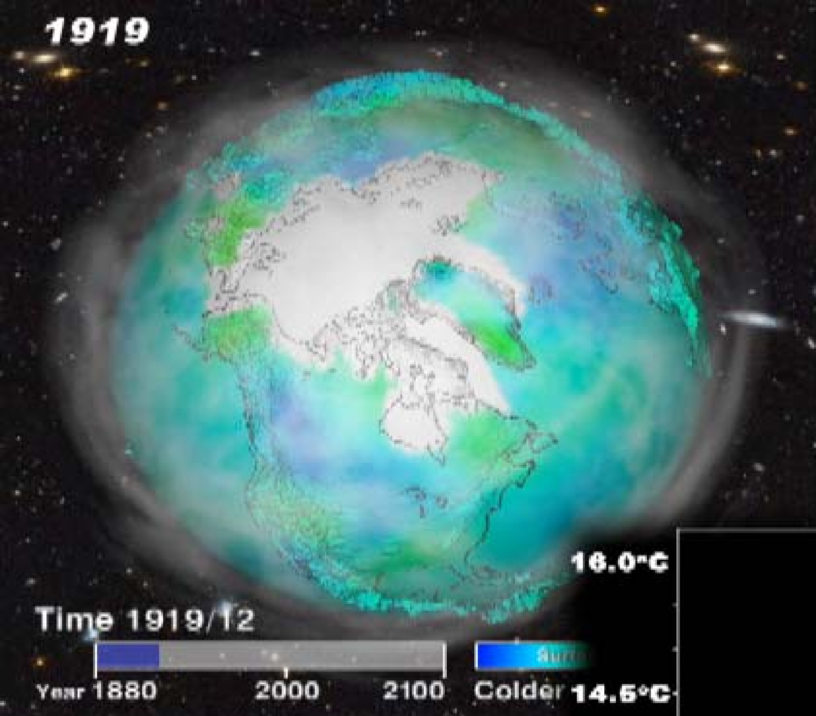
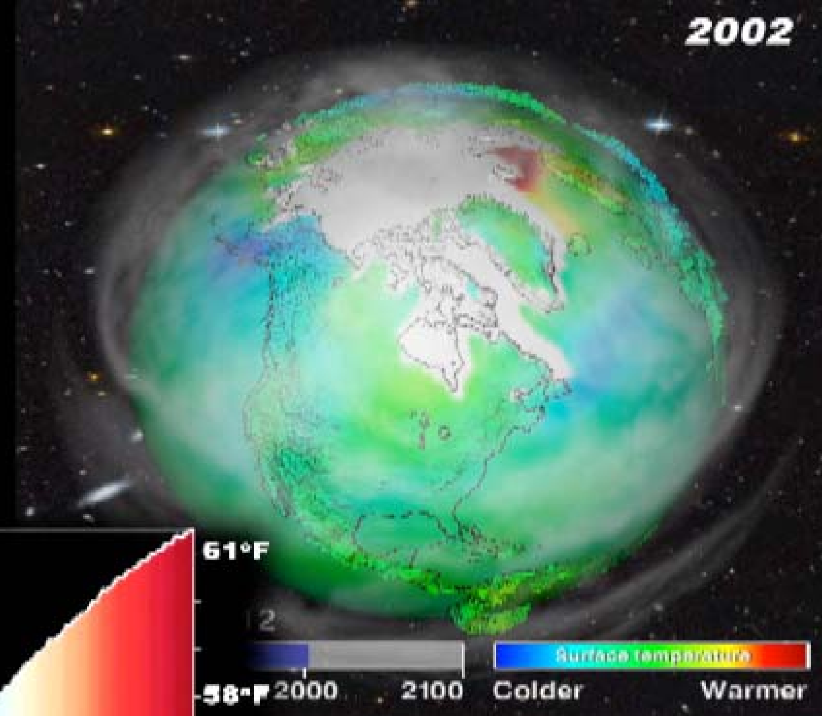
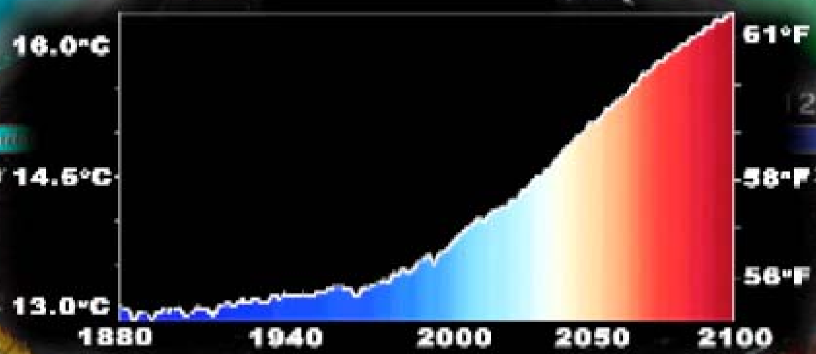
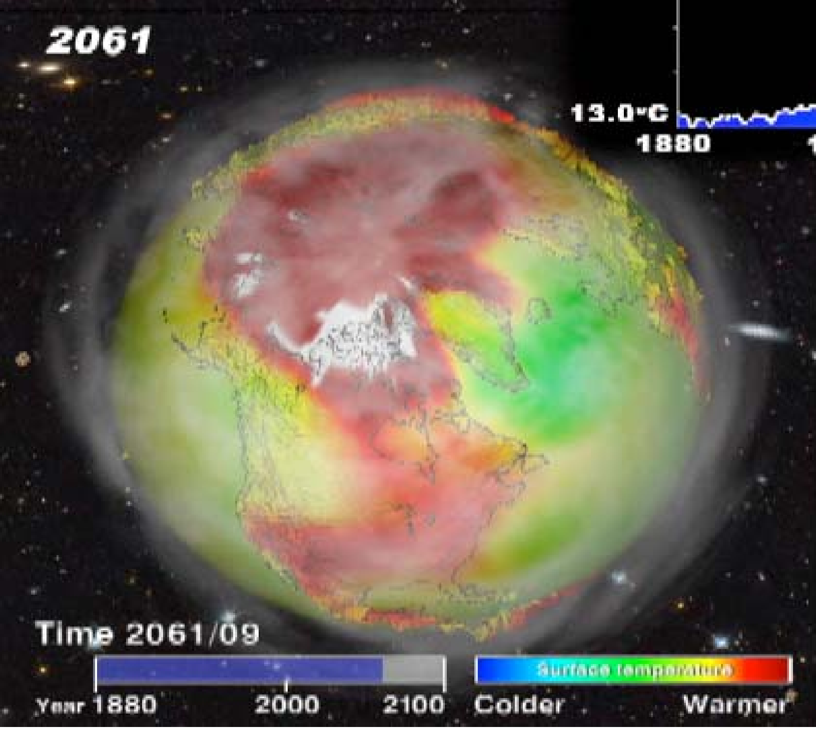
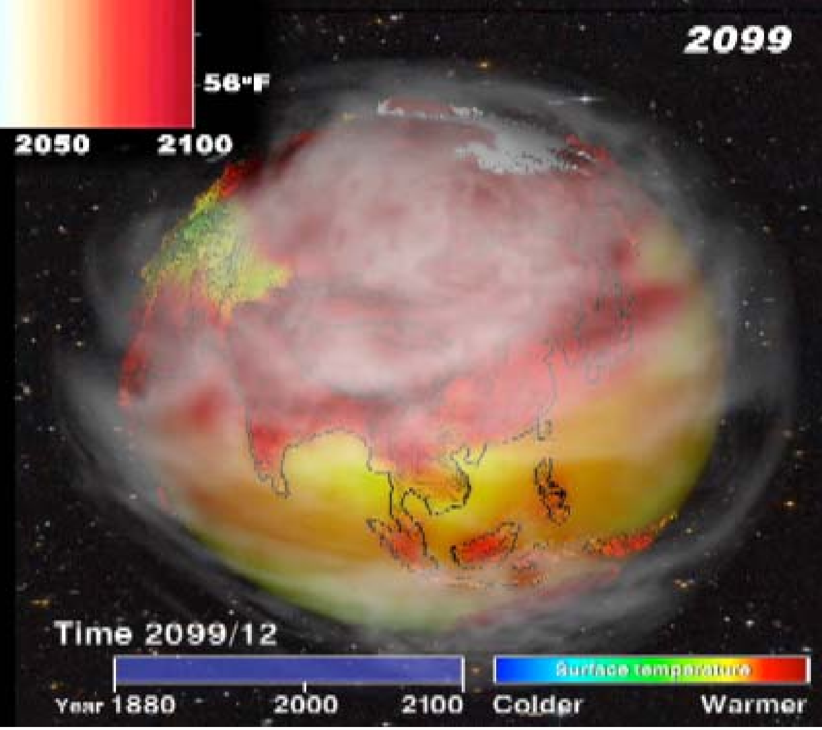
Through this visualization technology we can illustrate how the Earth's climate is warming.







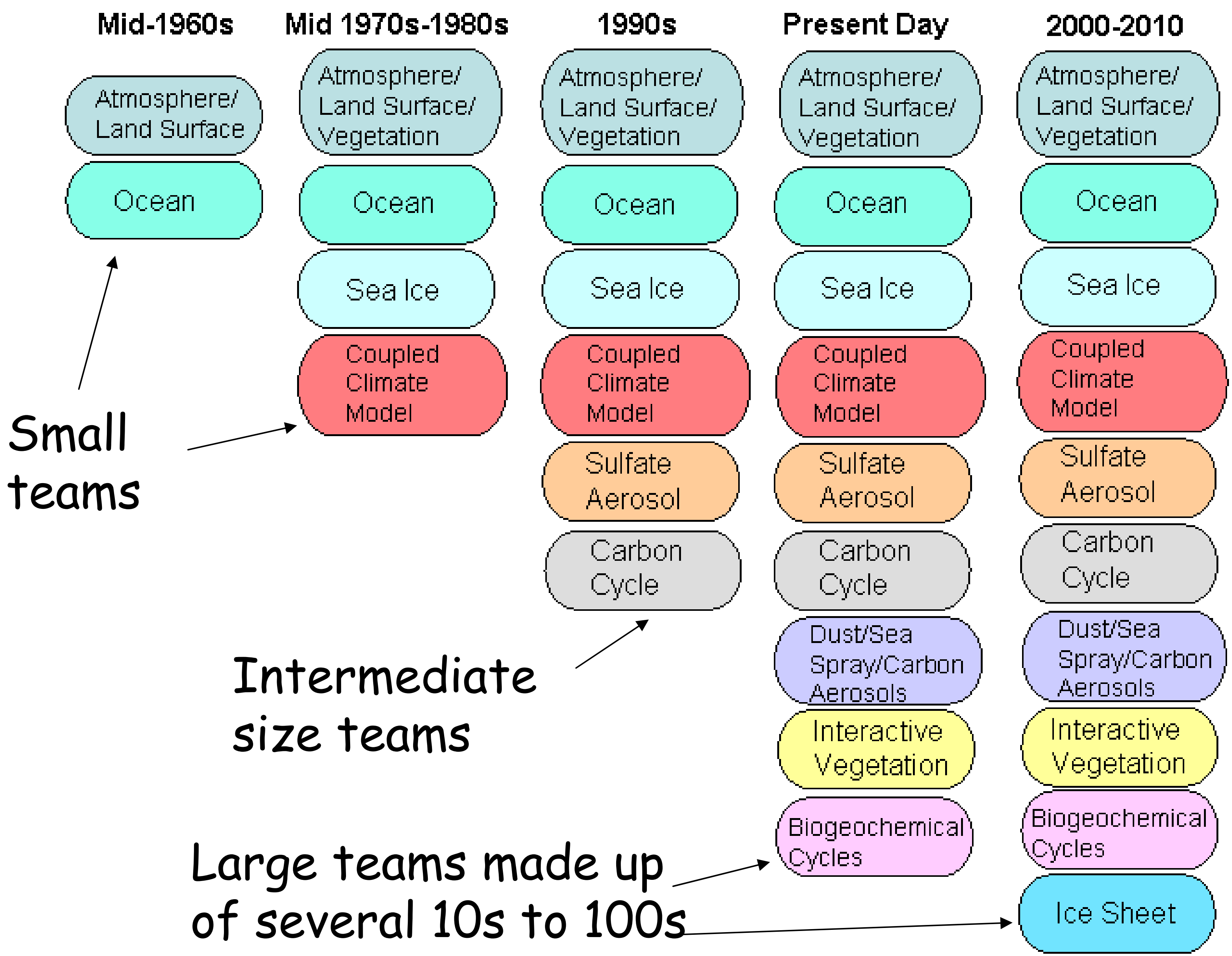




Crosscutting Issues

- Educate the next generation of climate scientists in extreme computing and train current scientists in the use of high-performance computers. Computer architectures have become increasingly complex, so it is important to have machines that are easier to use.
- Improve ability to predict changes in land cover, vegetation types, oceanic biology, and atmospheric and oceanic chemistry. We need to know how carbon, methane, and nitrogen cycles interact with climate change and how local and regional water, ice, and clouds change with global warming.
- Develop scalable algorithms that can use upcoming petascale and exascale architectures efficiently. New, robust techniques must be developed to enhance the input/output, storage, processing, visualization, and wide-area transport demands of exascale data sets.

Timeline of Climate Model Development



New Developments

- Coupling to glacier models…newest estimates of sea level rise are 39 cm by year 2100
- Coupling to extreme high resolution hydrological models to obtain future water management information
- Full coupling to integrative assessment models thus include economics, carbon emissions, population, and climate system change

Thank You to our sponsors and DOE representatives

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