Climate Modeling in a Changed World

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Weather vs Climate

Forecast Lead Time

- Outlook
- Guidance
- Threats Assessments
- Forecasts
- Watches
- Warnings & Alert Coordination

Forecasting Levels
- Minutes
- Hours
- Days
- 1 Week
- 2 Week
- Months
- Seasons
- Years

Benefits

Climate Change

- Boundary Conditions
- Forecast Uncertainty

Weather Prediction

Benefits

- Protection of Life & Property
- Flood Mitigation & Navigation
- Space Operation
- Transportation
- Fire Weather
- Hydropower
- Agriculture
- Reservoir Control
- Recreation
- Ecosystem
- Energy
- Health
- Commerce
- State/Local Planning
- Environment

NCAR

Trenberth
Surface temperature change relative to 1870-1899 baseline

Globally averaged surface temperature change (relative to 1870-1899 baseline)
Is the IPCC being too Alarmist?

If anything, we are being much too conservative!
Since AR4, the questions society is asking climate change science dramatically changed.

**WAS:** Is anthropogenic climate change occurring?

**NOW:** What will be the impact of anthropogenic climate change on coupled human and natural systems?

- Magnitude and speed... in specific regions and sectors?
- Direct and indirect impacts?
- Adaptation vs mitigation
- What are our options & limits?

> Addressing these new, much more complex, questions requires

- new approaches & priorities,
- new science capabilities,
- new collaborators/partners

> Vast improvements still req’d for Climate Models & Observation
## IPCC AR4 Modeling Centers & AR5 Timeline

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### NCAR CCSM4 & IPCC AR5 Estimated Timeline

- **Jun 08**: CCSM Workshop
- **CCSM4 development**
- **Oct 1 ’08**: CCSM4 Stage 2 Complete
- **Oct 1 ’08**: CCSM4 Stage 3 Validation
- **Feb 1 ’09**: Finalize CCSM4 Components
- **Feb 1 ’09**: CCSM4 1000yr Control
- **Jun 1 ’09**: CCSM4 Release at 2009 CCSM Workshop
- **Jun 1 ’09**: CCSM4 AR5 sensitivity/test runs
- **Jan 1 ’10**: Prepare Scenario Data
- **Jan 1 ’10**: Runs start
- **Jan 1 ’10**: IPCC AR5 Historical runs
- **Mar 1 ’10**: IPCC AR5 Near-term Hi-Res Scenario Runs
- **May 1 ’10**: IPCC AR5 Long Low-Res stabilization Runs
- **Dec 31 ’10**: Runs Finish
- **Feb 1 ’10**: Process Data
- **Jun 1 ’11**: All Data Submitted
- **Jun 1 ’11**: Paper Submission Deadline
- **Dec 15 ’11**: Paper Accepted Deadline
- **Feb 2013**: IPCC AR5 Release
New CCSM Components for CMIP5

• Aerosols
  – Direct and indirect effects
• Chemistry
  – Radiative and air quality issues
• Dynamic Vegetation
  – Historical evolution, future paths
• Carbon & Nitrogen Cycle
  – Ocean & land biogeochemistry
  – Anthropogenic (transient) land use/cover
• Land Ice Sheets
  – Sea level Rise & Abrupt Climate change
IPCC AR3 1998
IPCC AR4 2004 4TF
IPCC AR5 2010 500TF
CCSM Grand Challenge 2010 1PF

Global General Atm/Ocn Circulation
Continental Scale Flow
Carbon Cycle + BGC Spinups
Regional MJO/MLC Convergence
Sub-Regional Hurricanes

T42 2.8° • 310km
T85 1.4° • 160km
FV 1.0° • 110km
T170 0.7° • 78km
FV 0.5° • 55km
T340 .36° • 39km
FV 0.25° • 28km
FV 0.1° • 11km

Lawrence Buja (NCAR)
The CMIP experience: The importance of Community

From “Climate Models: A Users Guide” Daniel Farber, Sho Sato Professor of Law and Faculty Director of the California Center for Environmental Law and Policy, University of California, Berkeley.

•[Climate] Model predictions cannot be taken as gospel. There is considerable residual uncertainty about climate change impacts that cannot be fully quantified… The policy process should be designed with this uncertainty in mind.

•Economic models are much less advanced, and their conclusions should be used with caution. Unfortunately, economists are not always carefully about incorporating uncertainty into their policy recommendations.

•Climate scientists have created a unique institutional system for assessing and improving models, going well beyond the usual system of peer review. Consequently, their conclusions should be entitled to considerable credence by courts and agencies.
CMIP Data Services: Earth System Grid

ESG Goals

• Petabyte-scale data volumes
• Globally federated sites
• “Virtual Datasets” created through subsetting and aggregation
• Metadata-based search and discovery
• Bulk data access
• Web-based and analysis tool access
• Increased flexibility and robustness

Current ESG Sites

Primary ESG Servers
Mass storage, disk cache, and computation
PMEL: applications
NCAR: Climate change prediction and data archive
LBNL/NERSC: Climate data archive
LLNL: Model diagnostics and inter-comparison
USC/ISI: Globus, grid applications, and metadatabases
LANL: Climate and ocean data archive

Web and applications-based access to management, discovery, analysis, and visualization

ANL: Globus and grid applications
ORNL: Simulation and climate data archive

For AR5, ESG will be expanded to form a global virtual data center!

From: Earth System Grid Center for Enabling Technologies: (ESG-CET)
Briefing on Results: 
USGS Science Strategy to Support U.S. 
Fish & Wildlife Service Polar Bear 
Endangered Species Listing Decision:
The goal is to simulate the effects of climate change on precipitation across the intermountain West States and tropical cyclones, with a focus on the Gulf of Mexico.

- 36, 12 and 4 km domains nested into CCSM
- 1996-2005, then time slices out to 2050
- Multi-member ensembles for each period
- Dedicated time on NCAR IBM Power 6 (Bluefire) since July:
  - 24 nodes (~20% of total number of processors)
  - 36 (12) km simulations use 128 (256) processors per job
  - Will use 3.9M processor hours through 11/08
  - ~300 Tb of data (to date); 450 Tb total (including earlier runs)
Improving Predictions of Regional Changes in Weather and Climate

The Nested Regional Climate Model

High Resolution Climate Modeling

IPCC (2007)  ...  IPCC (2013)  ...  NRCM
“Science exists to serve human welfare. It’s wonderful to have the opportunity given us by society to do basic research, but in return, we have a very important moral responsibility to apply that research to benefiting humanity.”

Walter Orr Roberts, NCAR Founder
HPC dimensions of Climate Prediction

**New Science**
(new processes/interactions not previously included)

**Better Science**
(parameterization $\rightarrow$ explicit model)

**Spatial Resolution**
(simulate finer details, regions & transients)

**Timescale**
(Length of simulations $\times$ time step)

**Ensemble size**
(quantify statistical properties of simulation)

**Data Assimilation**
(decadal prediction/ initial value forecasts)

Lawrence Buja (NCAR) / Tim Palmer (ECMWF)
HPC dimensions of Climate Prediction

New Science

Better Science

Spatial Resolution (x*y*z)

Ensemble size

Timescale (Years*timestep)

Data Assimilation

ESM+multiscale GCRM

Code Rewrite

Earth System Model

Climate Model

Today

Terascale

Petascale

Exascale

Cost Multiplier

Regular

AMR

1000

160km

22km

0.2°

14°

1000

20min

3min

100yr*

1000yr*

1000yr* ?

2010

2018

1Km

1000

10

10

10

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Climate of the last Millennium

"Medieval Warm period" equivalent max-temperature reached in 1940

2000 - 2100: +2.5°C

Warmest year:
Obs: 1998
Simulation: 2000

CSM-Natural forcings only:
0.5 - 0.7°C colder than observations over 1990s:
This would represent the largest deviation from observations over the Millennium

Caspar Ammann
NCAR/CGD
Stage 1. 1870 control run: 1000 years with constant 1870 forcing: Solar, GHG, Volcanic Sulfate, O3


Stage 3. Future Scenarios: 4 2000-2100 IPCC Scenarios from end of historical run

Probabilistic Climate Simulations
2030: A Warmer and Wetter World
Temperature at 2030

Averages and Extremes
Precipitation at 2030

Averages and Extremes