The Community Earth System Model: A Framework for Collaborative Research

www.cesm.ucar.edu

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The Community Earth System Model
www.cesm.ucar.edu

Outline

• Community Use/Involvement

• Major Activities
  ✓ Model updates/releases
  ✓ CMIP5 simulations

• Selected Science Highlights
  ✓ Variability
  ✓ Past Climate
  ✓ Future Climate
Community Use and Involvement
A Community Resource

Over 3,000 sites from 130+ countries
>320 TB since January 2008
>1500 Registered Users of CESM1.0

January 2005 – May 2011

Courtesy Gary Strand

The Community Earth System Model
16th Annual Workshop

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NCAR ESG-CET portal cumulative download volume (GB)
Major Activities
**CESM Updates and Releases**

- CESM release mechanism is working (credit to SEWG):
  - First version of CESM and supporting documentation was released for community use in June 2010
  - Many and growing number of registered users
- Release updates support more science
  - Progressive support of greater model complexity and scientifically supported configurations in each update
  - Substantial increase in number of “out of box” configurations (104 in CESM1.03, nearly double those in CESM1.0)
  - CESM1.03 includes capability of running CMIP5 20th Century and RCP simulations as well as new science capabilities for several components: see “Notable Improvements” on release web page
- Increased capabilities and support for higher resolutions
  - All CESM components now support parallel I/O → key requirement
  - CESM1.03 supports 1/8° CAM/HOMME, 1/4° CLM, 1/10° POP/CICE
Much improved spatial pattern and magnitude of rainfall

- Western India and Bay of Bengal
- Longstanding wet bias over Yemen, Oman and Saudi Arabia
- Somali jet more realistic

 Courtesy Rich Neale
Resolution Impacts

JJA Precipitation

Diurnal Cycle
Timing (hour)
Amp. (mm/day)

Courtesy Rich Neale
Intense Atlantic hurricanes
(AMIP 1/4° CAM5)

Precipitation within 500 km of storm center

- Minimum pressure ~910 hPa and maximum winds ~140 mph
- Realistic “Cape Verde” storm (note dry eye)

Courtesy Julio Bacmeister
High-resolution Chemistry in CAM

Surface Ozone (July)

Philip Cameron-Smith, Art Mirin, Cathy Chuang, Dan Bergmann (LLNL)
CMIP-5 Simulations

- Major contribution of CESM and its partners to IPCC AR5 through simulations performed with both CCSM4.0 and CESM1.0
- CSL, NCAR and DOE computer resources decisive
- CMIP-5 Experimental Design (Taylor et al. 2009):
  
  A set of coordinated climate model experiments to:
  - address outstanding scientific questions from AR4
  - improve understanding of climate variability/change
  - provide estimates of future climate change

- CMIP-5 is a 5-year experimental design, but a significant fraction of the experiments will be done in time to be included in AR5
  - Initialized decadal prediction and long-term climate change
  - CCSM4.0 and CESM (CAM5, CAM-CHEM, WACCM, BGC) and paleoclimate (>600 Tb history output)
  - All Core, and most Tier 1 and 2, experiments complete & available (ESG)
  - Beginning to format and release to formal CMIP-5 data base too
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CESM Experiments and Diagnostics

CONTROL SIMULATIONS

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Many New Results and Capabilities

Special Collection J. Climate Papers:
http://www.cesm.ucar.edu/publications/pub.info.html

or at AMS:
http://journals.ametsoc.org/page/CCSM4/CESM1
Improved Variability
Pacific Variability: ENSO

Neale et al. (2008); Deser et al. (2011); Gent et al. (2011)
ENSO in CCSM4 and other models

Period (yrs) vs. $L_y$ (° latitude)

- **Observations**
  - Capotondi et al. (2006); Deser et al. (2011)

**Period** → freq of max spectral power of Niño3.4 SST

**$L_y$** → width of zonal wind stress anomalies
ENSO in CCSM4 and other models

Period (yrs) vs. $L_y$ (° latitude)

Period $\rightarrow$ freq of max spectral power of Niño3.4 SST

$L_y$ $\rightarrow$ width of zonal wind stress anomalies

CMIP3

CCSM3

Observations

Capotondi et al. (2006); Deser et al. (2011)
ENSO in CCSM4 and other models

Period (yrs) vs. \( L_y (\degree\text{latitude}) \)

- CCSM3
- CMIP3
- CM2.1
- Observations

Capotondi et al. (2006); Deser et al. (2011)

- Period: freq of max spectral power of Niño3.4 SST
- \( L_y \): width of zonal wind stress anomalies
Period $\rightarrow$ freq of max spectral power of Niño3.4 SST

$L_y$ $\rightarrow$ width of zonal wind stress anomalies

Capotondi et al. (2006); Deser et al. (2011)
Equatorial SST Composites

El Niño

Latitude/Time cross-sections

La Niña

Deser et al. (2011)
Atlantic Multidecadal Variability

CCSM4 Annual Mean SST and Surface T regressed on:

- AMV Index
- AMOC Index (2 yr lead)

Danabasoglu et al. (2011)
Anomalous Persistence of NAM

Winter Surface Temperature Anomalies

Total Observed

2010

NAM Influence

2010

2011

2011
Composite Differences of NAM Index

Strong and Weak Stratospheric Events

WACCM (2 AMIP runs)

ECMWF Reanalyses

22 strong, 65 weak events

12 strong, 36 weak events

Gerber et al. (2010)
“Compared to other global coupled models, CCSM4 exhibits relatively high skill in simulating intraseasonal oscillations. [It] has pronounced energy in the MJO band and is comparable to the best models [analyzed in Kim et al. 2009]
Past Climate
Northern Hemisphere Temperature
(Last Millennium 850-2005)

CCSM4 1° (black) compared to Proxies

Courtesy Bette Otto-Bliesner
Surface Temperature (1850-2005)

Annual Anomalies (°C)

Observations
CCSM4 Natural + Anthropogenic
CCSM4 Natural only

Meehl et al. 2011
Anthropogenic Aerosol Affects: CESM1 (CAM5)  
(late 20th century relative to pre-industrial climate)

Total aerosol change (optical depth)

- Increased aerosol burdens in SE Asia, Europe, NE North America, Brazil

Cloud water droplet number concentration (#/cc) at 850 hPa

- Increased cloud droplet number concentration; strongest over land
- Increased numbers of smaller drops; thus brighter low clouds with more liquid

Liquid water path (g/m²)

Low cloud affects: net cooling over 20th century
Surface Temperature (1850-2005)

- Observations
- CCSM4 (1°)
- CESM1 (CAM5 1°)
20th Century Surface Temperature Change

CCSM4 (1 deg)

OBSERVATIONS

More realistic regional warming
Impact of land cover change
(1976 to 2005 minus 1850-1879)

Lawrence, P. et al. (2011)
Arctic Sea Ice

Seasonal cycle

Sea ice extent [ Million km$^2$]

(a)

September extent

Jahn et al., 2011

- CCSM4 ensemble mean
- CCSM4 ensemble spread
- Bootstrap extent
- NSIDC extent (NASA)

Jahn et al. (2011)
CESM1: Prognostic Ocean Carbon Cycle

Ocean Inventory of Anthropogenic CO₂

Total
118 Pg C (±18)

90.3 Pg C

Courtesy Matt Long, ASP
Future Climate
Global Surface Temperature
(1850-2300)

Meehl et al. (2011)
Atlantic Meridional Overturning

![Graph showing Atlantic Meridional Overturning](image-url)

Meehl et al. (2011)

- rcp6.0
- rcp2.6
- rcp4.5
- rcp8.5

Sv ($10^6 m^3 s^{-1}$)

1900, 2000, 2100, 2200, 2300
North American Annual Surface T (°C)

(1900-2005)

Peacock (2011)
North American Annual Surface T (°C)

(1900-2100)

Peacock (2011)
Extremes: Number of Warm Days

End of 20th Century

> 80°F

> 90°F

> 100°F

End of 21st Century

Peacock (2011)
Near-surface permafrost degradation

- Improved distribution and active layer thickness
- ~25% slower thaw rates compared to CCSM3 due to improved soil physics

Lawrence et al. (2011)
Simulation of the 21st Century

September Arctic Ice Extent

Satellite Observations
CCSM4.0 (RCP 8.5)

Abrupt Changes

Vavrus et al. (2011)
Land Ice in CESM

Goal: Physically based estimates of land-ice contribution to SLR

Depth-averaged ice speed

Red regions: large outlet glaciers

- Jakobshavn (center left)
- Kangerdlugssuaq (center right)
- Helheim (lower right)

Surface mass balance (mm/yr)

Net accumulation

Net ablation

Courtesy of M. Vizcaíno
High Resolution Global Climate Simulations

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