Example Biases and Development Needs for CESM

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(On behalf of the CESM Project)
CESM Status

• CESM2 currently being assembled
  – CAM5.5, POP2+, CLM5, CICE5

• CESM has benefitted from previous CPTs
CESM Status

- CESM2 currently being assembled
  - CAM5.5, POP2+, CLM5, CICE5

- CESM has benefitted from previous CPTs

- Numerous biases remain within CESM

- We highlight examples of some important biases across different model components and the need for new model capabilities

- The examples given are areas where process understanding could lead to model improvements
Example: SST Bias

Anomalously Warm Coastal Upwelling Regions

Late 20th Century Relative to HadISST

(Danabasoglu et al. 2012)
Example: SST Bias

Biases associated with the Gulf Stream Separation and Path

(Danabasoglu et al. 2012)
Bias Example: Southern Ocean

Shallow Mixed Layer Depths

• CESM simulations have shallow mixed layer depths in the Southern Ocean
• This bias is not strongly dependent on the atmosphere or model resolution
• It is affected by vertical and lateral ocean mixing processes

Courtesy of Matt Long
Bias Example: Southern Ocean

Comparisons of simulated and observed ocean CFCs Indicate too little Southern Ocean uptake

Anthropogenic Carbon uptake bias

20\textsuperscript{th} century runs simulate too little carbon uptake

Courtesy of Matt Long
Bias Example:
Excessive Southern Ocean Absorbed Shortwave Radiation

CESM-CAM5 simulates excessive TOA Absorbed Shortwave Radiation

(Kay et al., 2014)
Cloud phase biases in atmosphere-only CAM5 runs (using simulator-enabled comparisons with CALIPSO)

Over the Southern Ocean: Not enough Liquid, Too much Ice
Bias Example: Snow on Sea Ice

CESM retains excessive snow cover on sea ice during summer
• High snow cover leads to high albedo
• Modifies surface albedo response and feedbacks
• This is an intermittent phenomena associated with ephemeral summer snowfall events

(Binary Example: Snow on Sea Ice)

- JAS Snow Depth
  1981-2000 CESM-LE

- Simulated Surface Albedo
- Obs-Based Albedo

((Light et al., 2015))
Many known snow processes are not incorporated into CESM

Processes influencing snow evolution

Courtesy of Matthew Sturm
Model Bias – Rainfall Spatial Distribution

Poor representation of orographic effects
- Resolution of complex topography
- Boundary layer processes over orography
- Cloud microphysics

Summer precipitation bias in percent
CCSM4 minus observations

Peacock, 2012
Model Bias – Rainfall Spatial Distribution

Summer Rainfall

Courtesy of Rich Neale
A need for new model capabilities
Example: Forest Vulnerability

Models like CESM with CLM-DGVM suggest widespread conifer die-off by 2100

• However, tree response to soil moisture deficits not well represented
• Forest loss is a complex problem that requires combined consideration of climate, hydrology, ecology, and plant physiology and diversity

(Courtesy of Dave Lawrence)
A need for new model capabilities
Plant hydrodynamics

• Current soil moisture stress parameterization has limited physical meaning.
• Measurements exist that would inform new plant hydrodynamics parameterizations
  • Sap flow
  • Physical properties of plant water use (wood density, conductance, water potential)
  • Satellite information on properties related to canopy/leaf water content.

(Courtesy of Dave Lawrence)
Summary

• Biases exist across all components of CESM
• There is also a need for new capabilities that will enhance process representation
• Improvements in both of these areas will increase the reliability of the simulated climate system response
• In many cases, process knowledge and observational information exist that could and should inform model developments in these areas
Questions?
Extra Slides
Model Bias – Rainfall Spatial Distribution

Summer Rainfall

Poor representation of orographic effects
- Resolution of complex topography
- Boundary layer processes over orography
- Cloud microphysics

TRMM (2001-2009)

CAM4 0.25° (1995-1998)

CAM4 1° (1991-1999)

Courtesy of Rich Neale
Model Bias: Rainfall frequency

- Common bias for many regions: Too much light rainfall, not enough heavy rainfall
- True even with 25km atmospheric model resolution
- Likely related to convection

Courtesy of Rich Neale
Consistent with comparisons to In-Situ Data

• Simulation of individual events with CESM using specified dynamics
• NSF G-V Aircraft flights over the Southern Ocean

Example: Research Flight: June 2011 Specified Dynamics version of CESM to simulate a particular day. Force winds and Temps. What do the clouds do?

Model Missing Supercooled Liquid

Courtesy of Andrew Gettelman

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October 2015
Bias Example: Southern Ocean Ventilation

Comparisons of simulated and observed ocean CFCs Indicate too little Southern Ocean uptake Has implications for simulated ocean heat and carbon uptake

Courtesy of Matt Long

CESM1-CAM5 20th Century Simulation

Translating Process Understanding to Improve Climate Models
October 2015
How vulnerable are Western US forests to climate change?

Models with simple representation of plant water use and mortality, like CLM-DGVM, suggest widespread conifer die-off by 2100.

But ... these results are likely unreliable; tree response to soil moisture deficits is represented in ad hoc way in land models. Forest loss is complex problem that requires combined consideration of climate, hydrology, ecology, and plant physiology and diversity.

Jiang et al. 2013
Process-Evaluations: In-Situ Data

- Can simulate individual events with CESM
- Example: NSF G-V Aircraft flights over the Southern Ocean looking at Cloud Microphysics

Example: Research Flight: June 2011 Specified Dynamics version of CESM to simulate a particular day. Force winds and Temps. What do the clouds do?
Section along **H4RF05** (Jun) Flight Track

**H4RF05 20110625 Number (L⁻¹)**

- **Blue Shading:** CESM Ice clouds
- **Green Shading:** CESM Liquid <0°C
- **Gray Shading:** CESM Liquid Clouds

**Model Missing Supercooled Liquid**

**H4RF05 20110625 NUM v. T**

- **CESM Ice**
- **HIPPO Ice**
- **CESM Liq**
- **HIPPO Liq**
- **HIPPO Liq <0°C**
- **CESM Liq <0°C**

Translating Process Understanding to Improve Climate Models

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October 2015

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Example: SST Bias

Coastal Upwelling Regions – Anomalously Warm

CESM-CAM5 Late 20th Century Relative to HadISST
Timeline for CESM2

Spring 2015
-
Decision on CAM5.5

CAM5.5 to developers
-
Interim versions of CLM5, POP2, CICE5, BGC, Chemistry, WACCM, Others

June 2015
-
Coupled simulations

Oct 1 2015
-
All components for FV-1° frozen by Oct. 1 2015

Spring 2016
-
Coupled simulations

June 2016
-
CESM2 FV-1°

Spring 2016
-
Coupled simulations

Coupled simulations
-
AMWG meeting in Jan-Feb 2016 to freeze CAM6

CESM2 SE-1/4°

- Code delivery
- Potential code delivery
- Potential code development
- Assembling and optimizing coupled model
CLM Development Timelines: The path towards CLM5/CESM2

- Ecosystem Demography (CLM-ED) development
- C, N refactor and param updates
- Extension of crops to global, fertilization
- Soil hydrology and snow refactor and updates (reactive transport modeling, water isotopes)
- Urban updates
- MOSART river model
- Flood/wetland full implement
- Dynamic landunits
- Land model processes benchmark system
- CAM5-CLM4.5BGC eval/tuning
- Fully coupled CESM1.2 BGC simulations
- CLM5(ED) ready for coupled sims 1/2017?
- CLM5 BGC eval/tune (fire, CH₄, flood, dust)
- Fully coupled BGC eval/tune of CLM5 and/or CAM5.5
- CLM5 control sims (BGC-crop, SP, ED?)
- CLM5 in CESM2 (CAM5.5, CAM6)
Development goals for CLM5

• Ecosystem Demography model – future biogeochemical core of CLM
  Goal: Globally functional CLM5(ED) for CESM2; CESM2 coupled runs within CMIP6 timeframe; will not be CESM2 default configuration

• Land cover and land use change
  Goal: Global / transient crop simulation with irrigation, fertilization, and cultivation of crops (land management) as default for historical runs
  More realistic land cover change impact on water and energy fluxes

• Carbon cycle
  Goal: Improved 20th century land carbon storage trend, response to N-additions
  Thoroughly revised Nitrogen cycle processes, improved wood harvest

• Hydrology
  Goal: Hydrology model that is closer to state-of-art understanding in hydrology
  New river model, updated groundwater, snow,

• Land-atmosphere chemistry coupling
  Goal: enhanced interactions, fire emissions, ozone damage to plants

• Water and carbon isotopes
Forcings:
- Greenhouse gases
- Manmade aerosols
- Volcanic eruptions
- Solar variability

Community Earth System Model

Forcings:

- Greenhouse gases
- Manmade aerosols
- Volcanic eruptions
- Solar variability

Biogeochemistry (Carbon-Nitrogen Cycle)

Land (CLM)

Surface Wave (WaveWatch)

Biogeochemistry (Marine Ecosystem)

Atmosphere (CAM)

Coupler (CPL)

Ocean (POP)

Chemistry (CAM-Chem)

High-Top Atm (WACCM)

Sea Ice (CICE)

Land Ice (CISM)
High-res tunings

Code speed-up

Energy changes

CAM5.4

High-res timeslice

CSLAM
Ice + mixed phase
Convection microphys.
TMS, Dust emissions

MG2

CLUBB+MG2

UNICON

Coupled Simulations

Coupled Simulations

Coupled Simulations

Coupled Simulations

CAM5.5

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