The CESM Large Ensemble Project
Inspiring New Ideas and Understanding

what is it and who made it happen?
THE COMMUNITY EARTH SYSTEM MODEL (CESM) LARGE ENSEMBLE PROJECT
A Community Resource for Studying Climate Change in the Presence of Internal Climate Variability


By simulating climate trajectories over the period 1920–2100 multiple times with small atmospheric initialization differences, but using the same model and external forcing, this community project provides a comprehensive resource for studying climate change in the presence of internal climate variability.
Figure 2. Global surface temperature anomaly (1961–90 base period) for the 1850 control, individual ensemble members, and observations (HadCRUT4; Morice et al. 2012).

Generate ensemble w/ round-off air temperature differences

Figure from doi:10.1175/BAMS-D-13-00255.1
First Days of the CESM-LE: From Deterministic Weather to Chaotic Climate

Figure from Vineel Yettella (University of Colorado)
The CESM-LE is a “Big Data” Project.

Original proposal was 1850 control runs and 30 ensemble members:
- 10,100 simulated years
- 21 million core-hours on NSF supercomputer Yellowstone
- 3 weeks per ensemble member
- 225 (600) Terabytes of post-processed (raw) output
Key contributions from many, but especially from...
From writing on whiteboards to our first ensemble member

By August 2013:
1) 1850 control run at year 1000
2) First ensemble member complete out to 2080, length of run diagnostics looking good.

Whiteboard from experimental design meeting
January 13, 2013
Support from the CESM leadership was essential...

**Marika Holland to Dave Hart on May 13, 2013**

“We are now in a position to start simulations that we have allocated under "Community Projects" in our CESM CSL proposal. ... Would it be possible to obtain project space for these community project runs?”

**Andy Mai to Jen Kay on June 6, 2013**

“I have noticed that the cesm0005 project space is now listed in the output from a "gladequota" command and is 400TB rather than 50. That's more like it!”
In October 2013, we had 7 ensemble members, we ate carrot cake, and ... we really jumped into the deep end.

E-mail on October 31, 2013 on monthly history files: “Delete 60 TB (Gary. Scary.).”
The University of Toronto contributed 7 additional ensemble members

October 15, 2013 e-mail from Paul Kushner

“Hi Jen and all,

Thanks for this email. It is timely because as you know I am writing a proposal to Compute Canada (a smallish size proposal that is due tomorrow) for U of Toronto and my group in particular to contribute to this project.

...”
The Pepsi Challenge contributed 3 additional ensemble members

September 10, 2013 e-mail from John Dennis

“Jen,

As you may know I have been looking into data-compression for climate data. I think the next step in this work is to get a climate scientist involved in a blind evaluation of the compressed data. I was thinking that you might be an ideal person because of your large ensemble project. ... “

Results - Baker, A. et al. submitted to GMD
As of January 2016...

42 Large Ensemble members are available on Yellowstone and on the Earth System Grid.

A Symphonic Wind Ensemble performing with 42 ensemble members
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general uses & applications
General uses & applications

Finding the forced response in the presence of internal climate variability

\[ A + B = C \]

Internal

Forced

Total

Ensemble Mean
General uses & applications

Interpreting observed trends ("Detection and Attribution")

- Proportion of Forced vs. Internal
- Time-of-emergence of forced (anthropogenic) component
General uses & applications

Robust characterization of internal climate variability (now and in the future)

- Extreme events
- Distributions

42 members to sample from: robust statistics
General uses & applications

Hierarchy of 1850 Control Runs

- Fully-coupled (2200 years)
- Slab-ocean (900 years)
- Atmosphere-only (2600 years)

- Robust baseline statistics
- Physical understanding
- Testing of null hypotheses
General uses & applications

Foundation for additional model experiments

- Medium (RCP4.5) Ensemble
- Perturbed ocean initial conditions
- Single forcing
- “Pacemaker”
- Regional climate models

6-hourly data saved for each ensemble member: 1996-2005, 2025-2034 and 2071-2080
General uses & applications

Interpreting spread within the CMIP5 multi-model archive

➤ Model differences
  (structural uncertainty)
  - potentially reducible as models improve

➤ Internal climate variability
  - irreducible (unpredictable)
General uses & applications

Informed model evaluation

- Improved knowledge of uncertainties arising from inadequate sampling
  - how many ensemble members do you need?

- Inherent challenges when comparing to short observational records

- Reference point for CESM2 development
General uses & applications

Informed model evaluation

Informed interpretation of nature

MODELS ↔ OBSERVATIONS

2-way street
Some specific examples
Some specific examples

- Interpreting observed trends
- Uncertainty in projected climate change

MODELS  2-way street  OBSERVATIONS
Some specific examples

- Interpreting observed trends
- Uncertainty in projected climate change
Winter Air Temperature Trends (1963-2012)

Observed  Simulation 7

°C / 50 years

Deser et al., J. Climate 2016
Winter Air Temperature Trends (1963-2012)

Observed  Simulation 7  Simulation 28

°C / 50 years

Deser et al., J. Climate 2016
Winter Air Temperature Trends (1963-2012)

Observed

Simulation 7

Simulation 28

Ensemble Mean

Forced Response

°C / 50 years

Deser et al., 2016 J. Climate
Winter Air Temperature Trends (1963-2012)

Observed

Simulation 7

Simulation 28

3.5°C

~ equal parts forced and unforced

Ensemble Mean

Forced Response

Deser et al., 2016 J. Climate
Some specific examples

- Interpreting observed trends
- Uncertainty in projected climate change

MODELS  2-way street  OBSERVATIONS
September Arctic Sea Ice Extent

Member #13
Observations
the CESM Large Ensemble Project
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lessons learned related to CMIP
CMIP = ensemble of opportunity = spread due to differences in model physics and internal variability

Initial condition ensemble (e.g., CESM-LE) = spread due to internal variability alone

QUESTION: When does CMIP spread = CESM-LE spread?

ANSWER: It happens. More than I ever thought it would...
Stippling on the historical and near-future CMIP5 maps indicates standard deviations that are statistically different than the CESM-LE for the corresponding period.

Figure from Kay, Deser et al. doi:10.1175/BAMS-D-13-00255.1
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Website:
www2.cesm.ucar.edu/models/experiments/LENS