Ensembles of ensembles:
Using multiple Large Ensembles to assess robust changes in climate and climate variability

Flavio Lehner and Clara Deser (and CLIVAR WG)
National Center for Atmospheric Research
Large Ensembles are useful for:

✓ Assessment of Signal, Noise, and Signal-to-Noise
Applications of (multiple) Large Ensembles

Large Ensembles are useful for:

- Assessment of Signal, Noise, and Signal-to-Noise
  (many contributors!)
Large Ensembles are useful for:

- Assessment of Signal, Noise, and Signal-to-Noise
- Variability and changes in variability (Pendergrass et al., 2017; Stevenson et al., 2012; Alexander et al., 2018; Screen and Deser 2018; etc.)
Applications of (multiple) Large Ensembles

Large Ensembles are useful for:

- Assessment of Signal, Noise, and Signal-to-Noise
- Variability and changes in variability
- Methodological testbed (Deser et al., 2016; Lehner et al., 2017; Guo et al., 2019; McKinnon and Huybers 2016; Coats and Mankin 2017; etc)
**Applications of (multiple) Large Ensembles**

Large Ensembles are useful for:

- Assessment of Signal, Noise, and Signal-to-Noise
- Variability and changes in variability
- Methodological testbed
- Extreme/compound events \(\text{(Otto et al., 2018; van der Wiel et al., 2019; etc)}\)

CESM LE paper (Kay et al. 2015)
Cited by 567

Citation count by year:
- 2014: 5
- 2015: 1
- 2016: 2
- 2017: 2
- 2018: 2
- 2019: 2
New initiative and tool

CLIVAR Working Group on Large Ensembles

- Public data repository with 7+ models with >15 ensemble members
New initiative and tool

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• Development of an “observational” large ensemble for temperature, precipitation, and SST
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- Design of protocol for next generation of Large Ensembles
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- Design of protocol for next generation of Large Ensembles
- Do science on open questions that require Large Ensembles:
  - Move beyond mean state model validation to validation of subseasonal to decadal variability
  - Assess forced changes in variability
  - Explicit statistics of extreme and compound events
  - ...

...
New initiative and tool

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July 24-26, 2019 | Boulder, CO

The Large Ensembles Workshop

Fostering usage of large initial-condition ensembles with Earth System Models to advance understanding of natural climate variability, anthropogenic climate change, and their impacts.

Abstracts due March 8, 2019
usclivar.org/meetings/large-ensembles-workshop

Scientific Organizing Committee
Clara Deser (NCAR; co-chair)
Keith Rodgers (ICCP; co-chair)
Pedro DiNezio (U Texas Austin)
Jennifer Kay (CU Boulder)
Flavio Lehner (NCAR)
Nikki Lovenduski (CU Boulder)
Karen McKinney (UCLA)
Isla Simpson (NCAR)
Bookend maps

PR Trends annual 1951-2010

Observations (GPCC)
Bookend maps

PR Trends annual 1951-2010

High pattern correlation
Bookend maps

PR Trends annual 1951-2010

Observations (GPCC)
Signal-to-noise (here: signal)

TAS Ensemble Mean Trends annual 1951-2010

NCAR CESM1 (40)  CCCma CanESM2 (50)  CSIRO Mk36 (30)  GFDL CM3 (20)
GFDL ESM2M (30)  EC-EARTH (16)  MPI ESM-MR (100)

Grid point near Sydney, Australia
Signal-to-noise (here: noise)

TAS Trends Standard Deviation annual 1951-2010

NCAR CESM1 (40)
CCma CanESM2 (50)
CSIRO Mk36 (30)
GFDL CM3 (20)
GFDL ESM2M (30)
EC-EARTH (16)
MPI ESM-MR (100)

Temperature (°C)
Signal-to-noise

TAS Trends Signal-to-Noise annual 1951-2010

NCAR CESM1 (40)  
CCma CanESM2 (50)  
CSIRO Mk36 (30)  
GFDL CM3 (20)

GFDL ESM2M (30)  
EC-EARTH (16)  
MPI-ESM-MR (100)

Signal-to-noise

0  .5  .75  1  2  3  4  5  11.753
Signal-to-noise (here: signal)

PR Ensemble Mean Trends annual 1951-2010

NCAR CESM1 (40)  CCCma CanESM2 (50)  CSIRO Mk36 (30)  GFDL CM3 (20)

GFDL ESM2M (30)  EC-EARTH (16)  MPI ESM-MR (100)

Grid point near Sydney, Australia

Precipitation (mm day\(^{-1}\) 60yr\(^{-1}\))

Relative density

Trend (mm day\(^{-1}\) 60\(^{-1}\) years)
Signal-to-noise

PR Trends Signal-to-Noise annual 1951-2010

NCAR CESM1 (40)  
CCma CanESM2 (50)  
CSIRO Mk36 (30)  
GFDL CM3 (20)  
GFDL ESM2M (30)  
EC-EARTH (16)  
MPI ESM-MR (100)

Signal-to-noise

0  .5  .75  1  1.5  2  2.5  3  5.573
How many ensemble members do I need?

annual tas change (2005-2014) - (1951-1960)

NCAR CESM1 (40)  CCCma CanESM2 (50)  CSIRO Mk36 (30)
GFDL ESM2M (30)  EC-EARTH (16)  MPI ESM-MR (100)  GFDL CM3 (20)

Min. no. of ens. members to detect significant change
How many ensemble members do I need?

Annual pr change (2005-2014) - (1951-1960)

- NCAR CESM1 (40)
- CCCma CanESM2 (50)
- CSIRO Mk36 (30)
- GFDL CM3 (20)
- GFDL ESM2M (30)
- EC-EARTH (16)
- MPI ESM-MR (100)

Min. no. of ens. members to detect significant change

3, 6, 9, 12, 15, 20, 30, 40
Hawkins & Sutton-type figures

Original Hawkins & Sutton figures:
- Used 4th order polynomial to define forced response
- Assumed internal variability to be constant

Sources of uncertainty in decadal mean
How are LEs informing future decision making?

• Illustrate where there is agreement/disagreement on mean changes
Changes in variability

How are LEs informing future decision making?

- Illustrate where there is agreement/disagreement on mean changes
- Enable assessment of changes in variability

* The author is not actually advocating for any of this
Large Ensembles remain useful tools to study climate variability and change.

Thanks! flehner@ucar.edu
Large Ensembles remain useful tools to study climate variability and change.

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Repository access:
1. Through UCAR’s Cheyenne supercomputer:
   • /glade/collections/cdg/data/CLIVAR_LE/
     ✓ canesm2_lens, cesm_lens, csiro_mk36_lens, ec_earth_lens, gfdl_cm3_lens, gfdl_esm2m_lens
     ✓ mpi_lens
     ✓ oLens_mckinnon

2. Through Climate Data Gateway (CDG):
   • Register here if you don’t yet have a CDG (former ESG) account:
     https://www.earthsystemgrid.org/ac/guest/secure/registration.html
   • Data can be found here: https://www.earthsystemgrid.org/dataset/ucar.cgd.ccsm4.CLIVAR_LE.html
     ✓ canesm2_lens, cesm_lens, csiro_mk36_lens, ec_earth_lens, gfdl_cm3_lens, gfdl_esm2m_lens
Fig. 1: signal-to-noise maps
Bookend maps

TAS Trends annual 1951-2010

Temperature (°C 60yr⁻¹)
Bookend maps

PR Trends annual 1951-2010

Precipitation (mm day$^{-1}$ 60yr$^{-1}$)