Interpreting Model Results

Clara Deser
National Center for Atmospheric Research
Boulder, CO

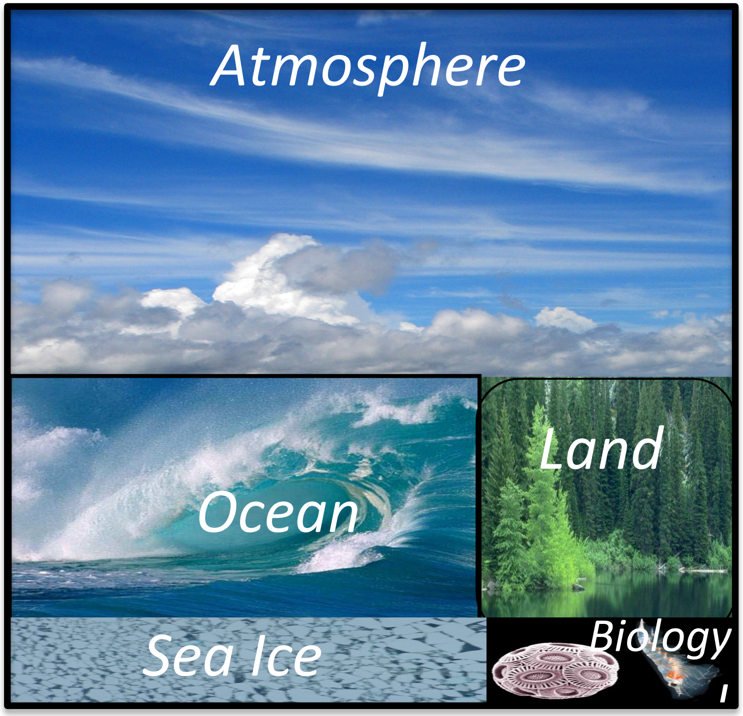
CESM Tutorial, 12 August 2016

Interpreting Model Results

1) What kind of model?
2) What kind of simulation?
3) What can (and can't) you learn from it?

Types of Models and Experiments

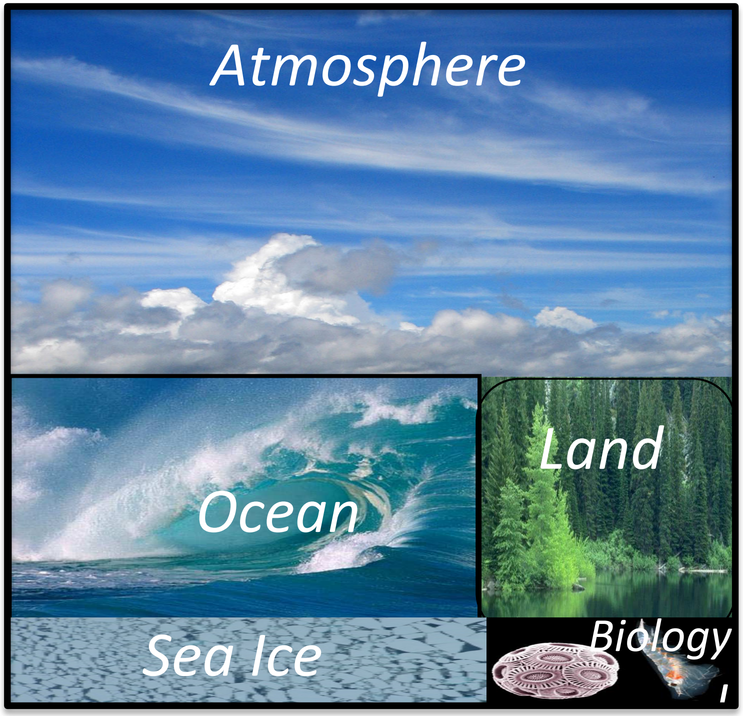
Free-running coupled climate models



Examples:
NCAR Community Earth System Model (CESM)
"CMIP5" models used in IPCC Assessment Reports

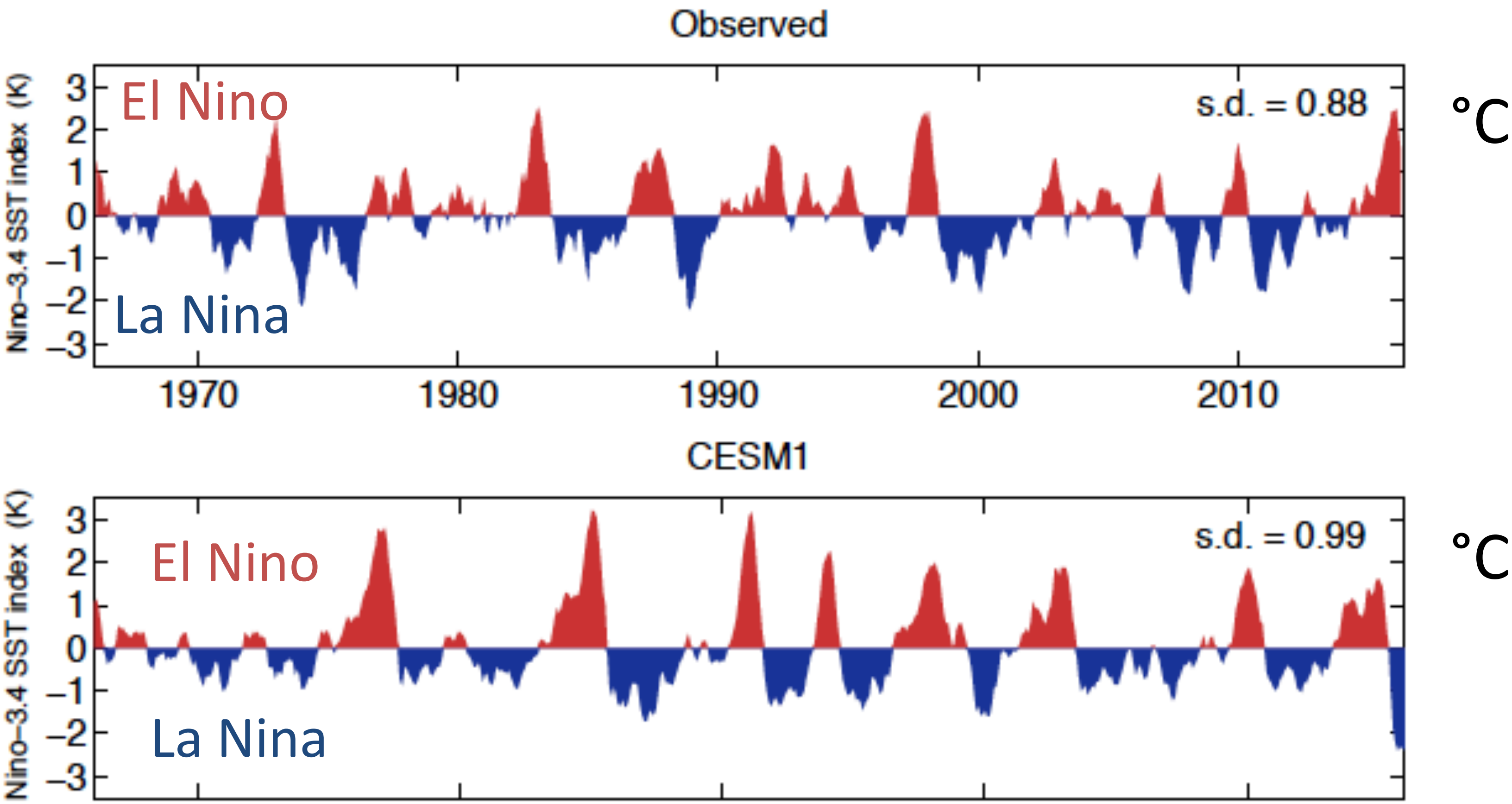
Types of Models and Experiments

Free-running coupled climate models



Produce their own internally-generated sequences of climate variability (i.e., ENSO, decadal) which need NOT match the observed sequence. However, the statistics of the variability should match observations.

Eastern Tropical Pacific Sea Surface Temperature Anomalies



DiNezio et al., 2016: *Climate Dynamics*

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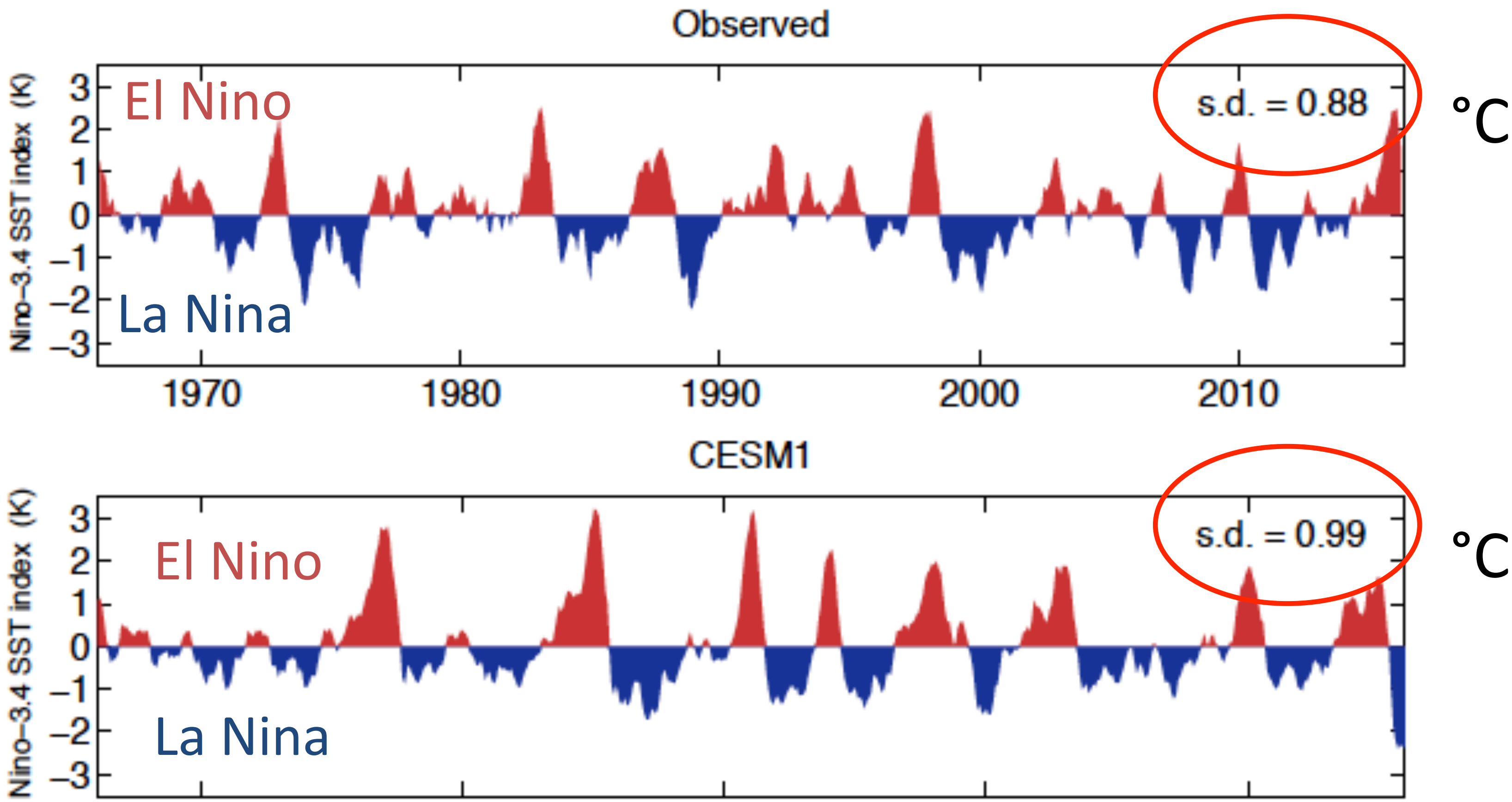


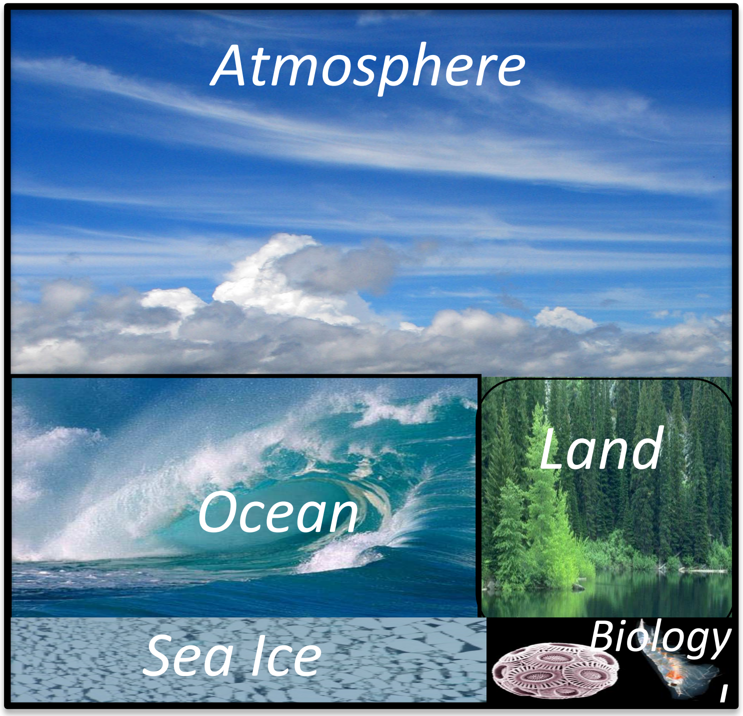
Are the characteristics of ENSO well simulated?

amplitude, period, spatial pattern, mechanisms

Need long enough simulations to evaluate.

Types of Models and Experiments

Free-running coupled climate models

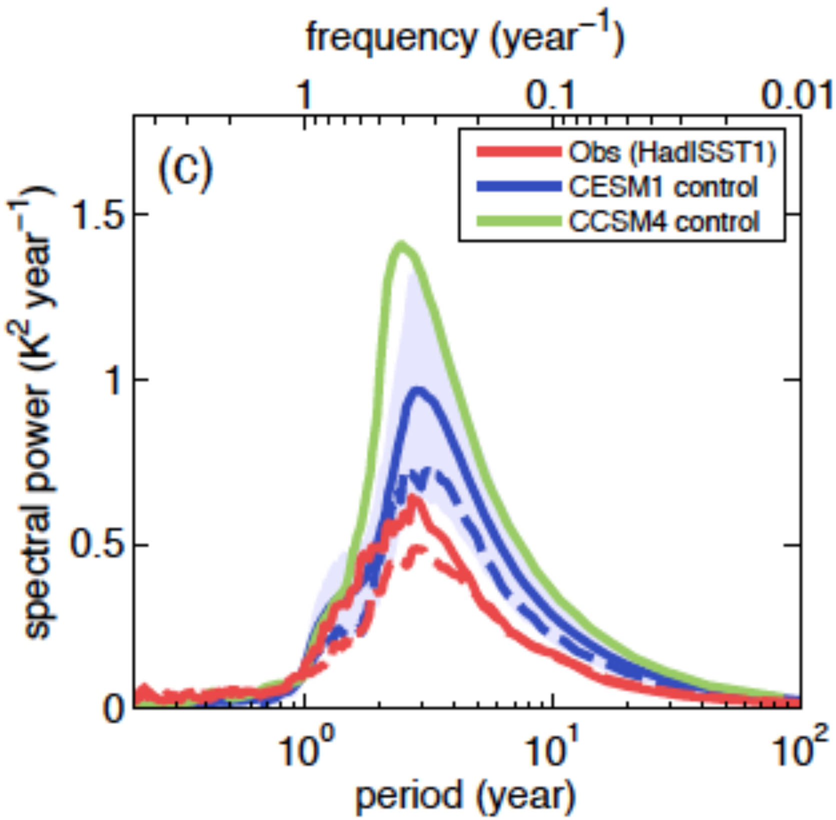


“Control” simulations (1000+ years)

No changes in radiative forcing (e.g., fixed GHGs).

>> Robust statistics of the model’s internal variability in an unchanging climate (e.g., ENSO, PDO, AMO, MJO, …).

Power Spectrum of Nino3.4 SST Index



HadISST observations
1870-1969 (first 100 years)
1916-2015 (second 100 years)

CESM1 control simulation
(eighteen 100-year segments)

CCSM4 control simulation
(thirteen 100-year segments)

DiNezio et al., 2016: *Climate Dynamics*

Explore more examples from the Climate Variability Diagnostics Package

CVDP | CLIMATE VARIABILITY DIAGNOSTICS PACKAGE

The Climate Variability Diagnostics Package (**CVDP**) developed by NCAR's Climate Analysis Section is an analysis tool that documents the major modes of climate variability in models and observations, including ENSO, Pacific Decadal Oscillation, Atlantic Multi-decadal Oscillation, Northern and Southern Annular Modes, North Atlantic Oscillation, Pacific North and South American teleconnection patterns. Time series, spatial patterns and power spectra are displayed graphically via webpages and saved as NetCDF files for later use. The package also computes climatological fields, standard deviation and trend maps; documentation is provided for all calculations. The CVDP can be run on any set of model simulations (as long as the files meet CMIP5 output metadata requirements), allowing inter-model comparisons. Observational data sets and analysis periods are specified by the user. The CVDP Data Repository contains CVDP output for most CMIP3 and CMIP5 model simulations. A few examples are linked below, including those from the 40-member CESM1 Large Ensemble Project.

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CVDP INFO

- Home
- News
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- Known Issues

www2.cesm.ucar.edu/working-groups/cvcwg/cvdp

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NCAR UCAR | CGD's Climate Analysis Section

Climate Variability Diagnostics Package

Methodology | Metrics Table
Climatological Period Used: Full
Input Namelists: OBS | Models
Derived Namelists: MOC | PR | PSL | SIC NH | SIC SH | SND | TAS | TS
Created: Fri Feb 5 06:12:08 MST 2016
CVDP Version 4.0.0

CESM1-LENS Control Comparison

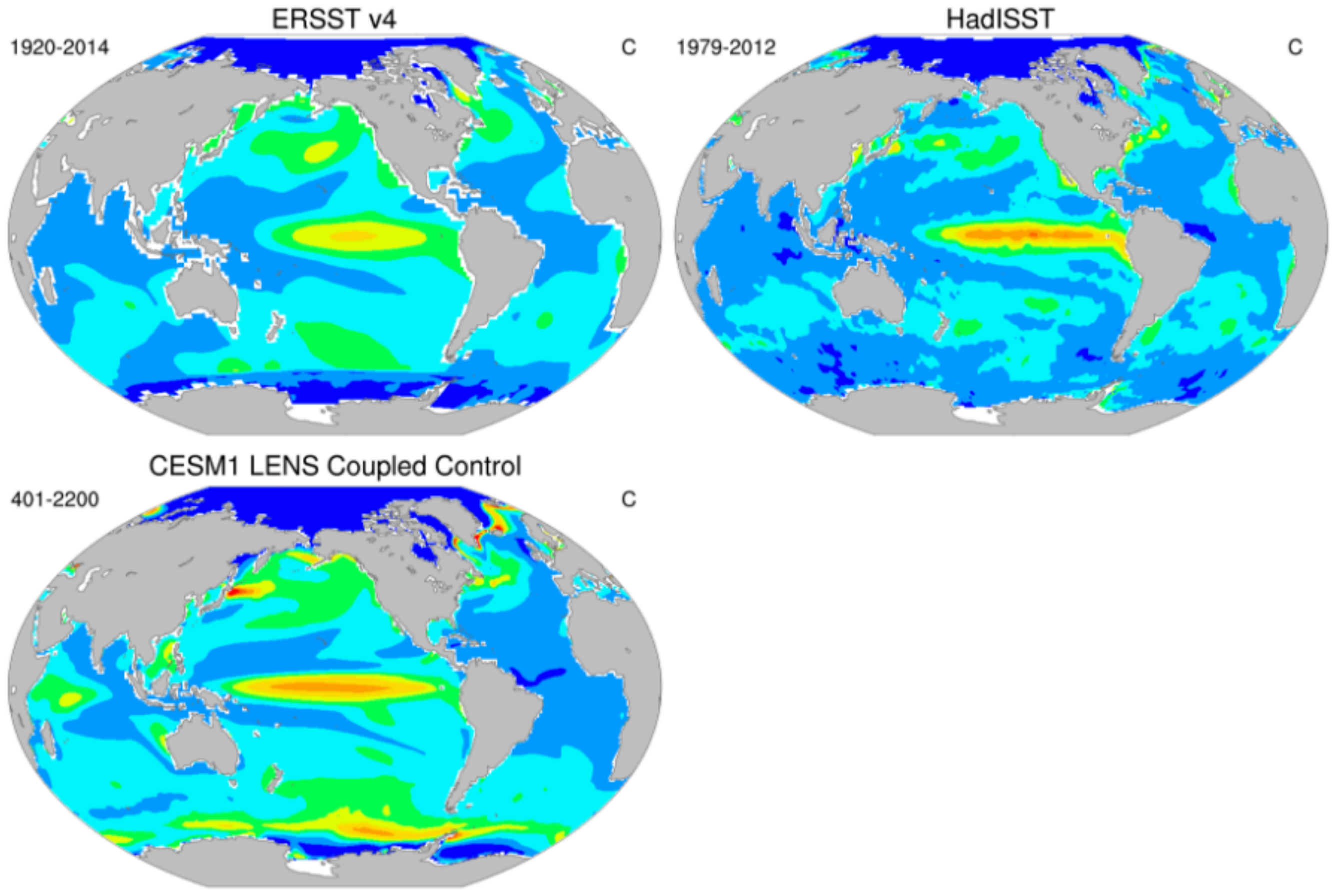
Means

SST	DJF	MAM	JJA	SON	Annual
TAS	DJF	MAM	JJA	SON	Annual
PSL	DJF	MAM	JJA	SON	Annual
PR	DJF	MAM	JJA	SON	Annual
[PR]	DJF	MAM	JJA	SON	Annual
SND	DJF	MAM	JJA	SON	Annual
SIC NH	DJF	MAM	JJA	SON	Annual
SIC SH	DJF	MAM	JJA	SON	Annual

Standard Deviations

SST	DJF	MAM	JJA	SON	Annual
TAS	DJF	MAM	JJA	SON	Annual
PSL	DJF	MAM	JJA	SON	Annual
PR	DJF	MAM	JJA	SON	Annual
SND	DJF	MAM	JJA	SON	Annual
SIC NH	DJF	MAM	JJA	SON	Annual
SIC SH	DJF	MAM	JJA	SON	Annual

SST Standard Deviations (DJF means)



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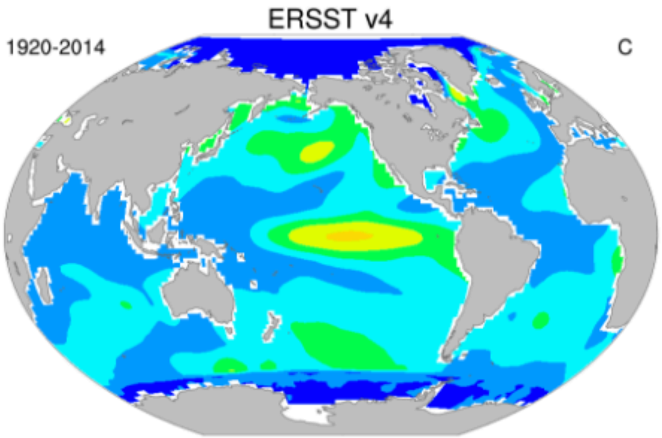
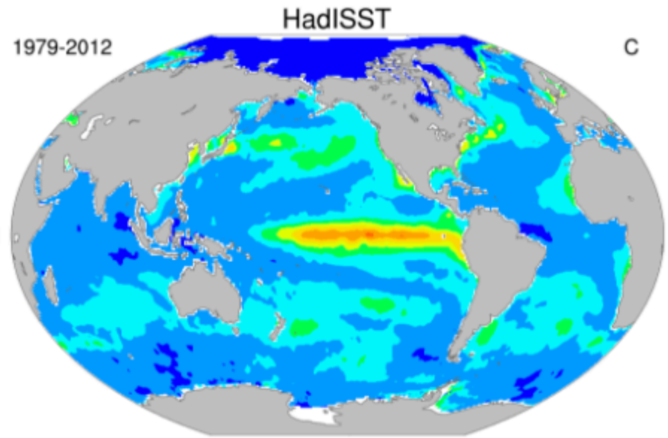
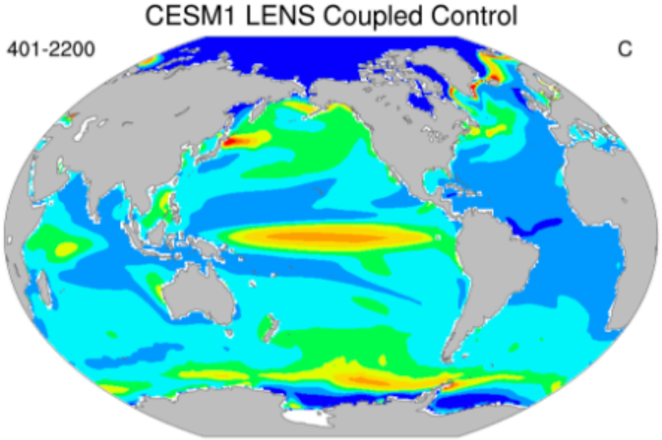






Spread in Observations

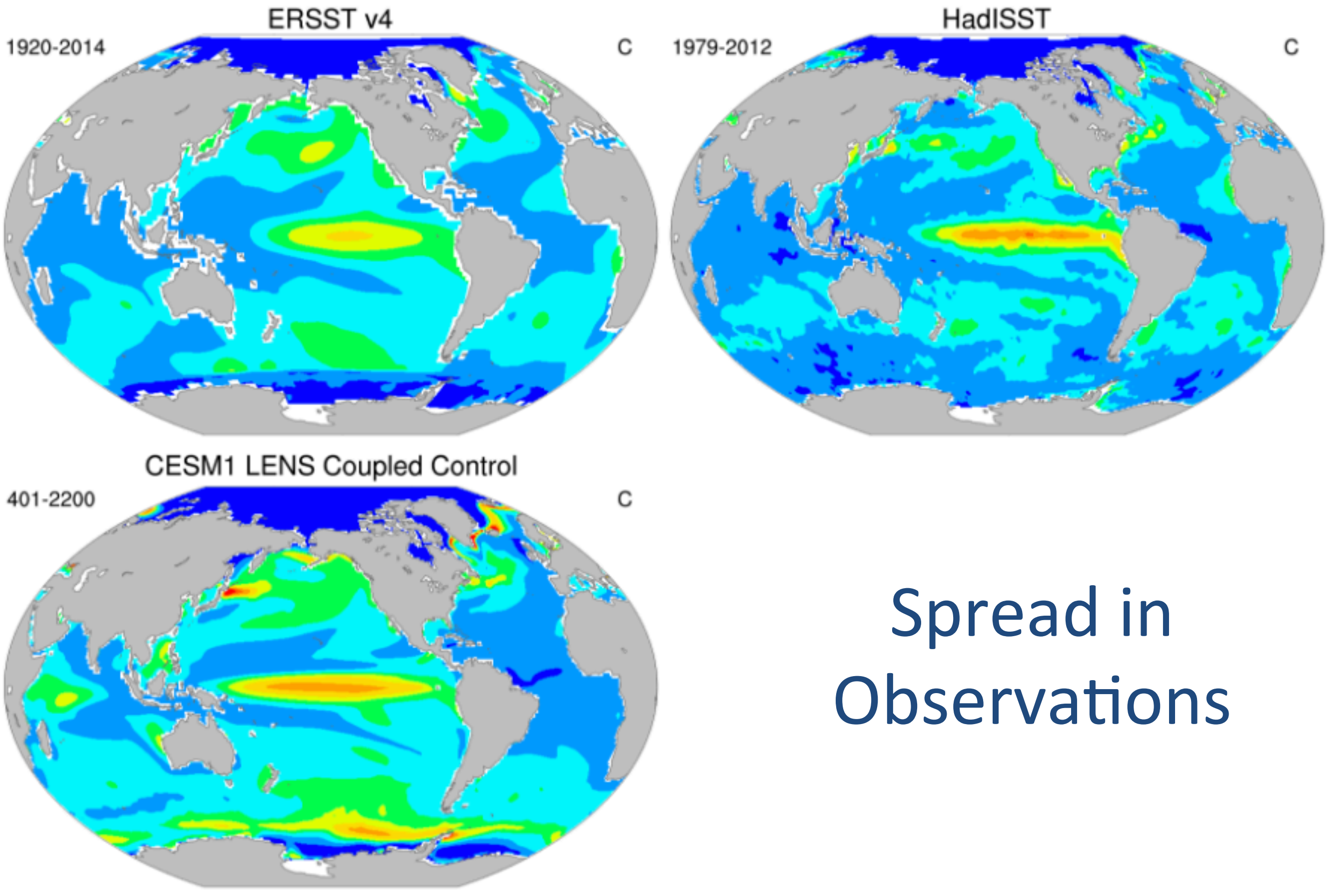
Which Observational Data Set to Use?

The only data portal that combines data discovery, metadata, figures and world-class citable expertise

https://climatedataguide.ucar.edu

Schneider, Deser, Fasullo and Trenberth: EOS, 2013

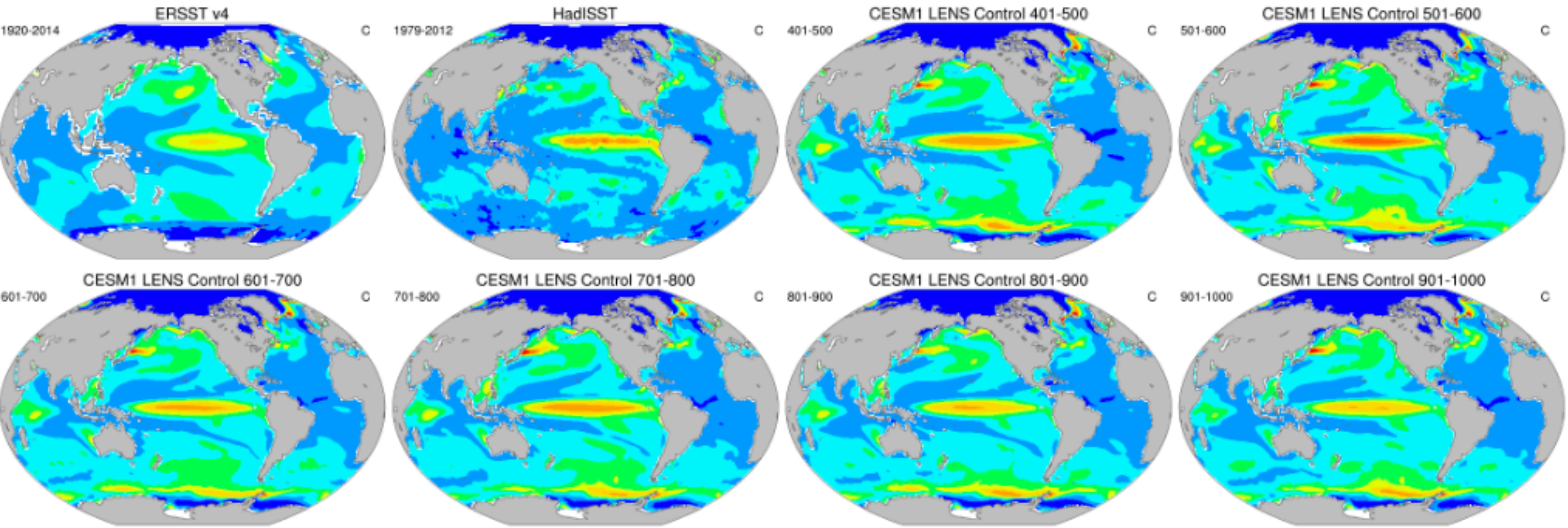
SST Standard Deviations (DJF means)



Spread in Observations

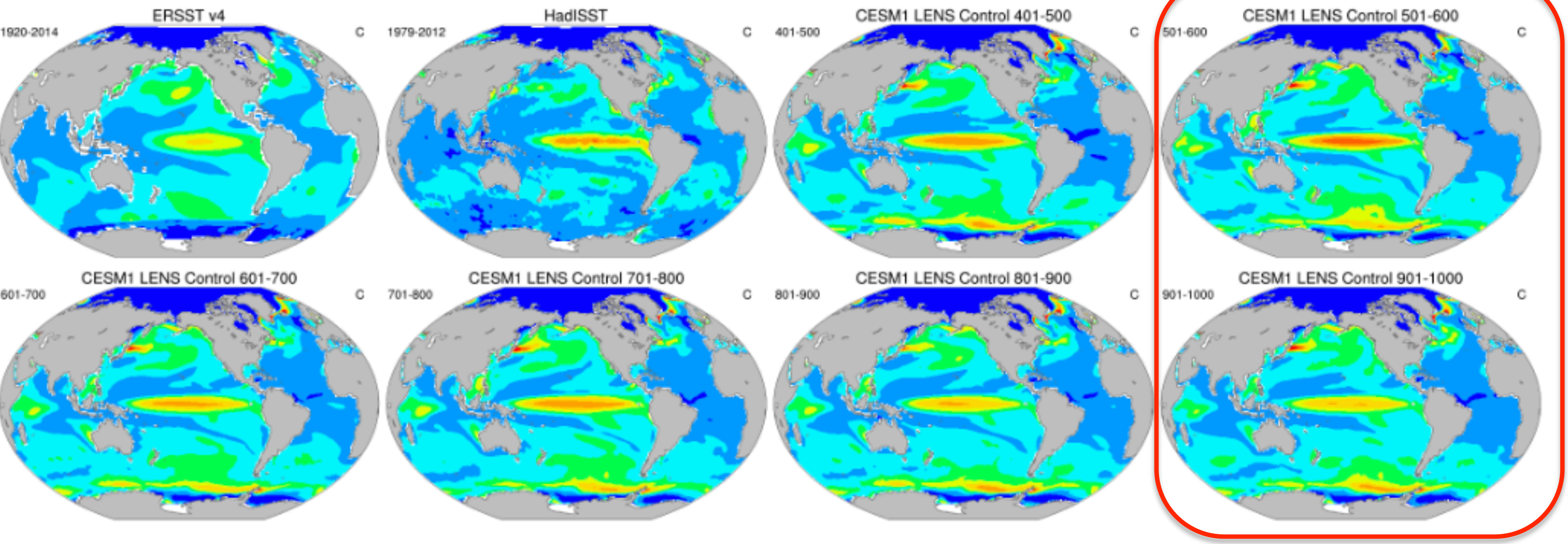
Observational record is only about 100 years long, so might want to look at 100 year segments of the control run for a more informative comparison.

SST Standard Deviations (DJF means)



Large spread in 100 year segments of the control run.

SST Standard Deviations (DJF means)



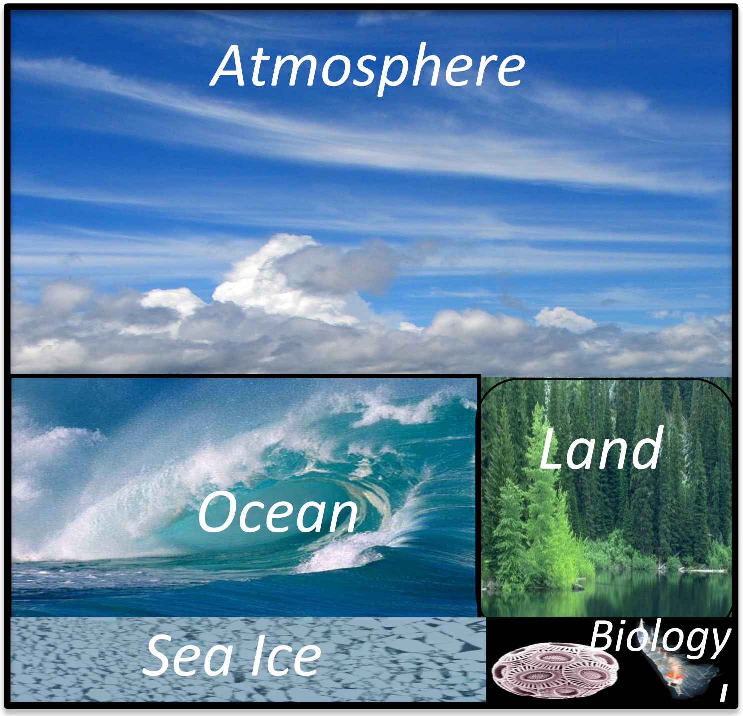
Large spread in 100 year segments of the control run.

Brings up challenges with model evaluation:

- How well do we know the observed variability?
- How do we validate our models given the limited span of the observational record?

Types of Models and Experiments

Free-running coupled climate models



"Historical" simulations (generally 1850-2005)

Prescribed evolution of radiative forcing (GHG, aerosols, volcanoes, solar irradiance, stratospheric ozone, ...).

>> Internal variability PLUS response to radiative forcing.

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CVDP INFO

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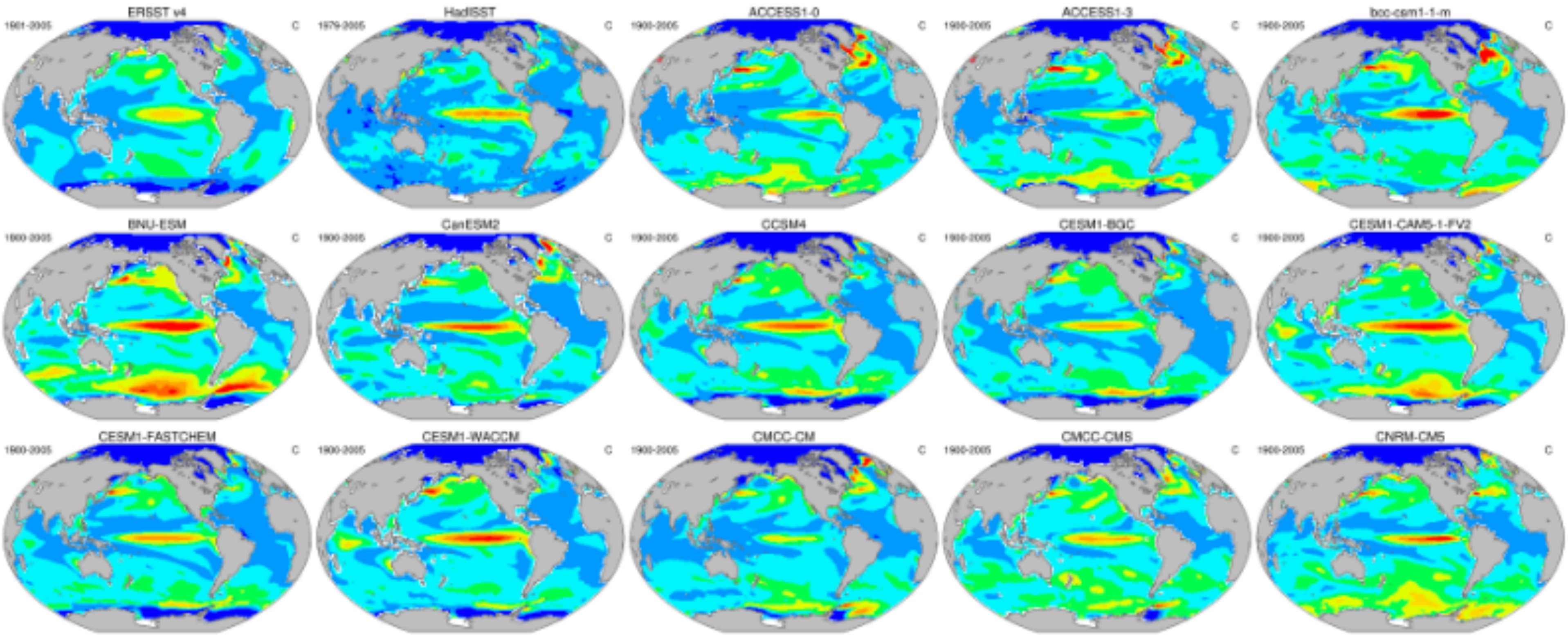
38 CMIP5 models (1 run each) *vs*. 40 CESM1 simulations

What's the difference?

SST Standard Deviations (DJF means) 1900-2005



CMIP5 models:
Large inter-model spread in variability

Due to different model physics or limited sampling?

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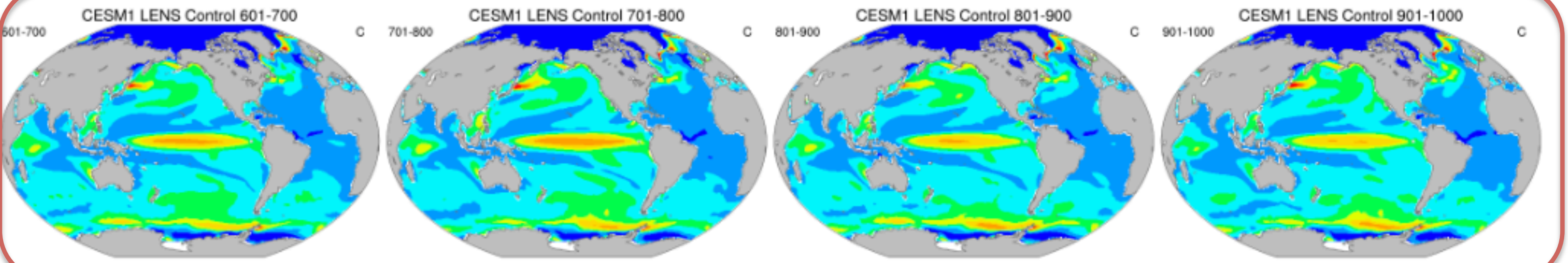
CESM1 control vs. historical simulations

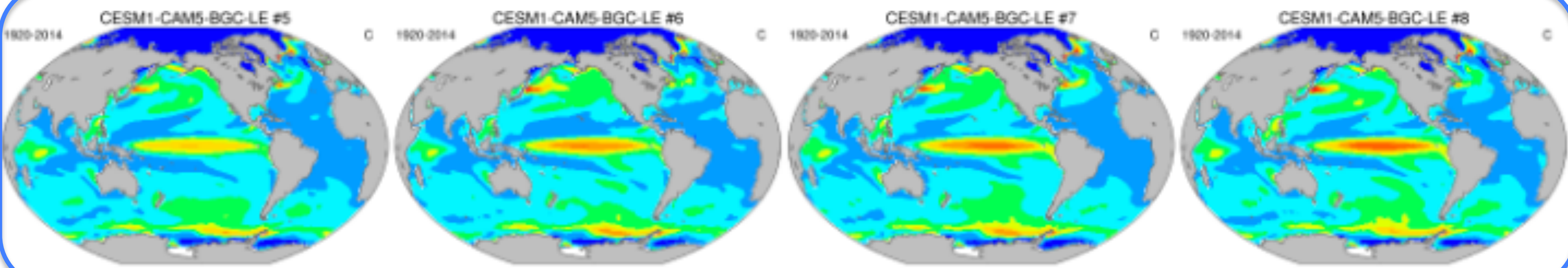
What's the difference?

SST Standard Deviations (DJF means)

Four 100-year segments of CESM1 Control



Four 100-year CESM1 Historical simulations



SST Standard Deviations (DJF means)

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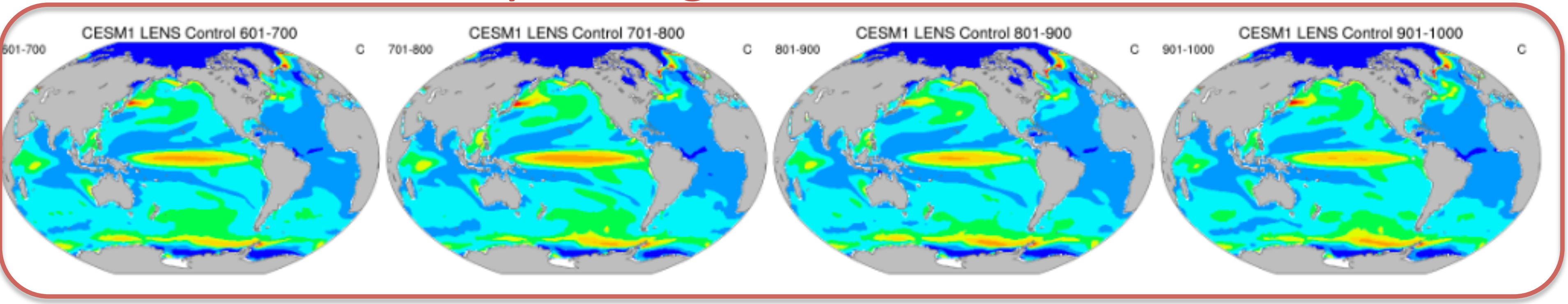

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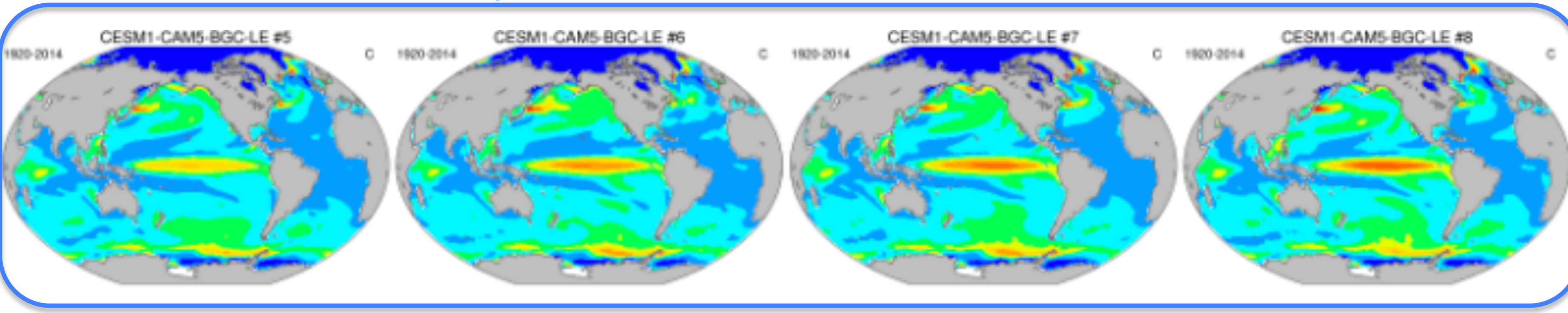
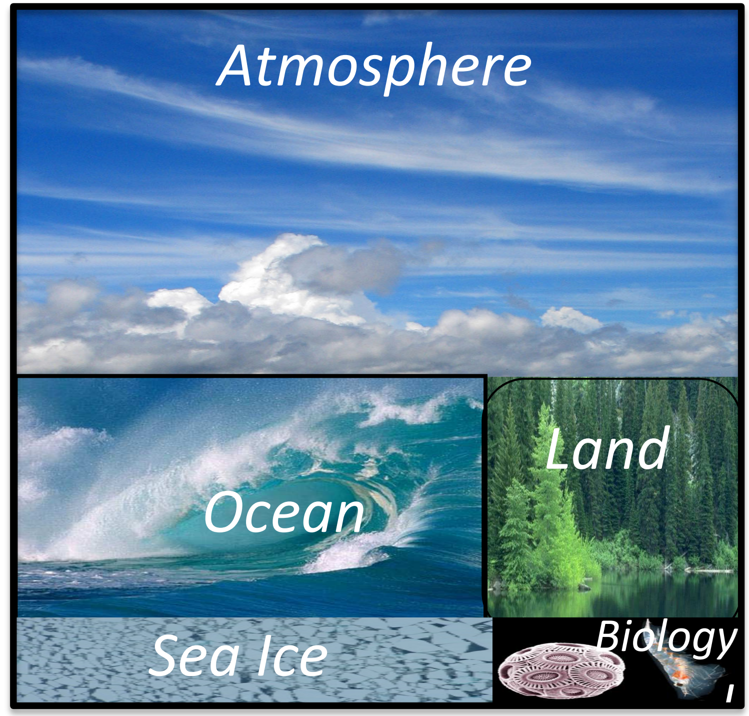


Does ENSO increase due to radiative forcing?

Need many runs (large sample size) to determine.

Types of Models and Experiments

Free-running coupled climate models



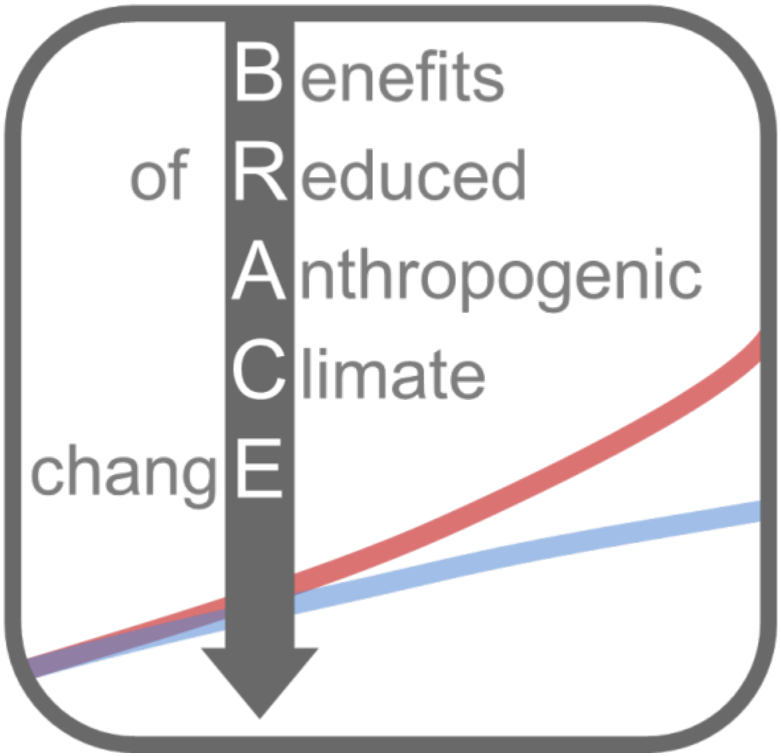
Projections (present-2100)

RCP2.5, RCP4.5, RCP8.5 radiative forcing scenarios

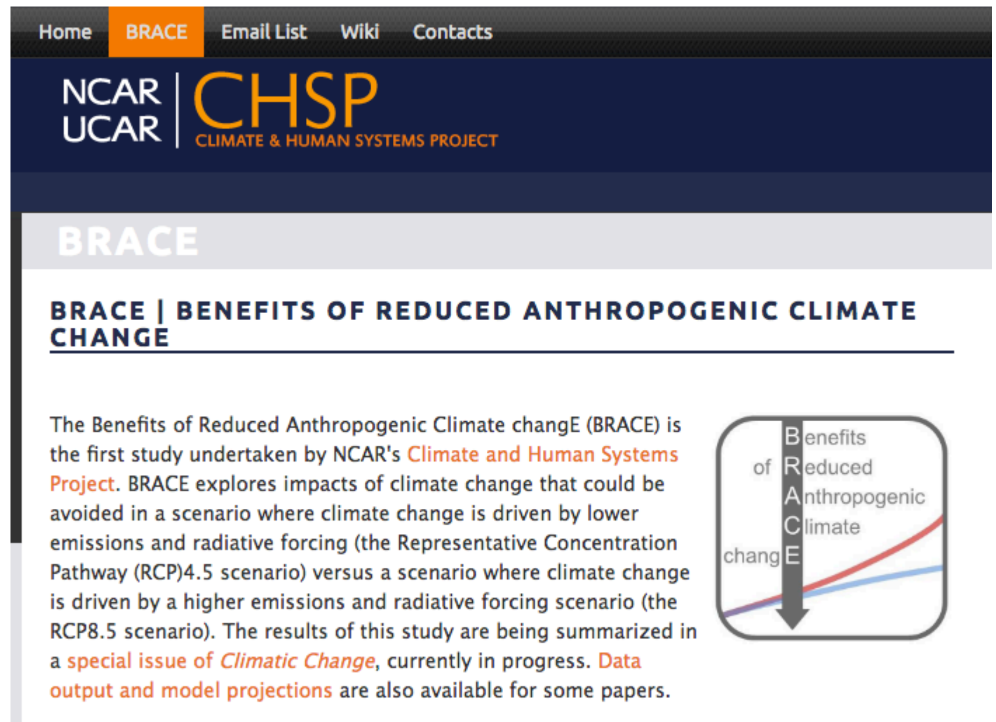
Internal variability PLUS response to radiative forcing.

40 RCP8.5 & 15 RCP4.5 simulations with CESM1

Robust assessment of benefits of climate mitigation



Climate and Human Systems Project

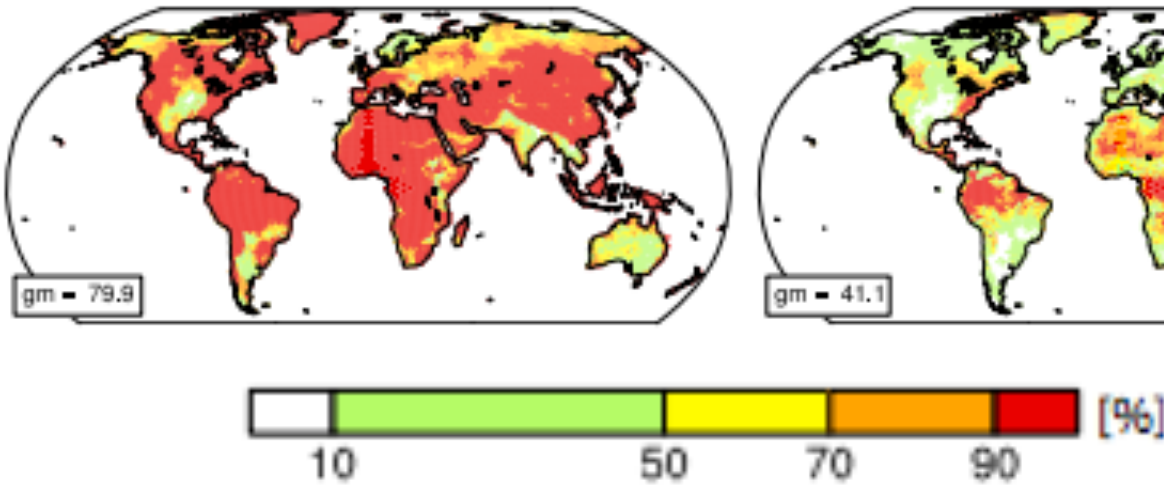


//chsp.ucar.edu/brace-benefits-reduced-anthropogenic-climate-change

Probability of Exceeding the Historical (1920-2012) Record Summer Temperature in 2061-2080

RCP8.5 RCP4.5

80% 41%



Lehner, Deser and Sanderson, 2015: *Climatic Change*

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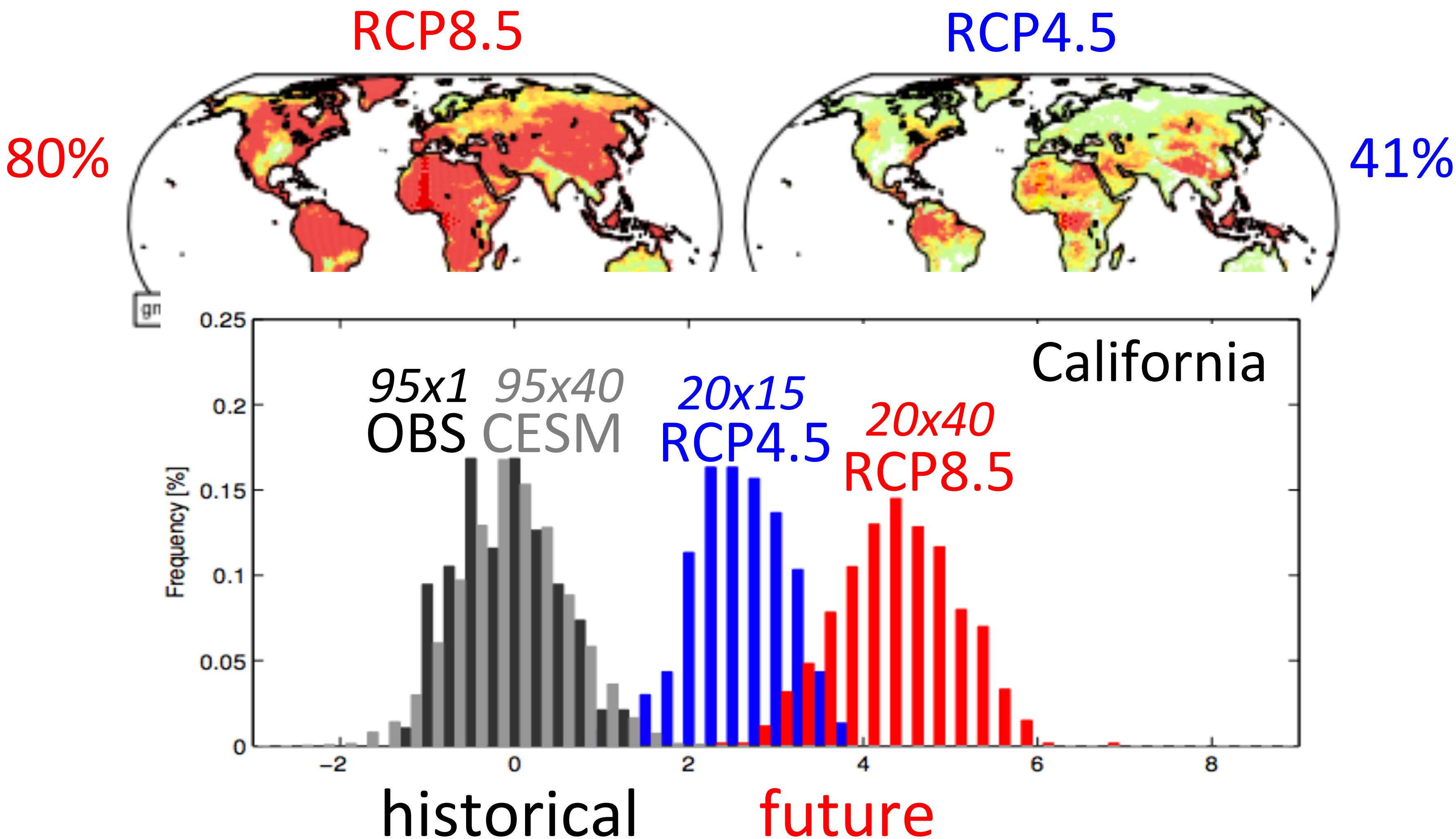

Types of Models and Experiments

Free-running coupled climate models

Constrained model simulations

Types of Models and Experiments

Free-running coupled climate models

Constrained model simulations

Hypothesis testing
Physical understanding
Direct comparison with nature (attribution)

Types of Models and Experiments

Free-running coupled climate models

Constrained model simulations

Coupled Models or Component Models *(atmosphere, ocean)*

Hypothesis testing
Physical understanding
Direct comparison with nature (attribution)

Some Examples of
Constrained Model Simulations

Response to Tropical Pacific SST variations

Atmospheric Model
Coupled Model

Some Examples of Constrained Model Simulations

Response to Tropical Pacific SST variations

Atmospheric Model

- Specify observed SST evolution in the Tropics, climatological seasonal cycle elsewhere.

"AMIP" protocol

TOGA: Tropical Ocean, Global Atmosphere

Some Examples of Constrained Model Simulations

Response to Tropical Pacific SST variations

Coupled Model

- Nudge model's SST anomalies to observations in the eastern Tropical Pacific, allow full ocean-atmosphere coupling elsewhere.

"Pacemaker" protocol

Some Examples of Constrained Model Simulations

Response to Tropical Pacific SST variations

Coupled Model

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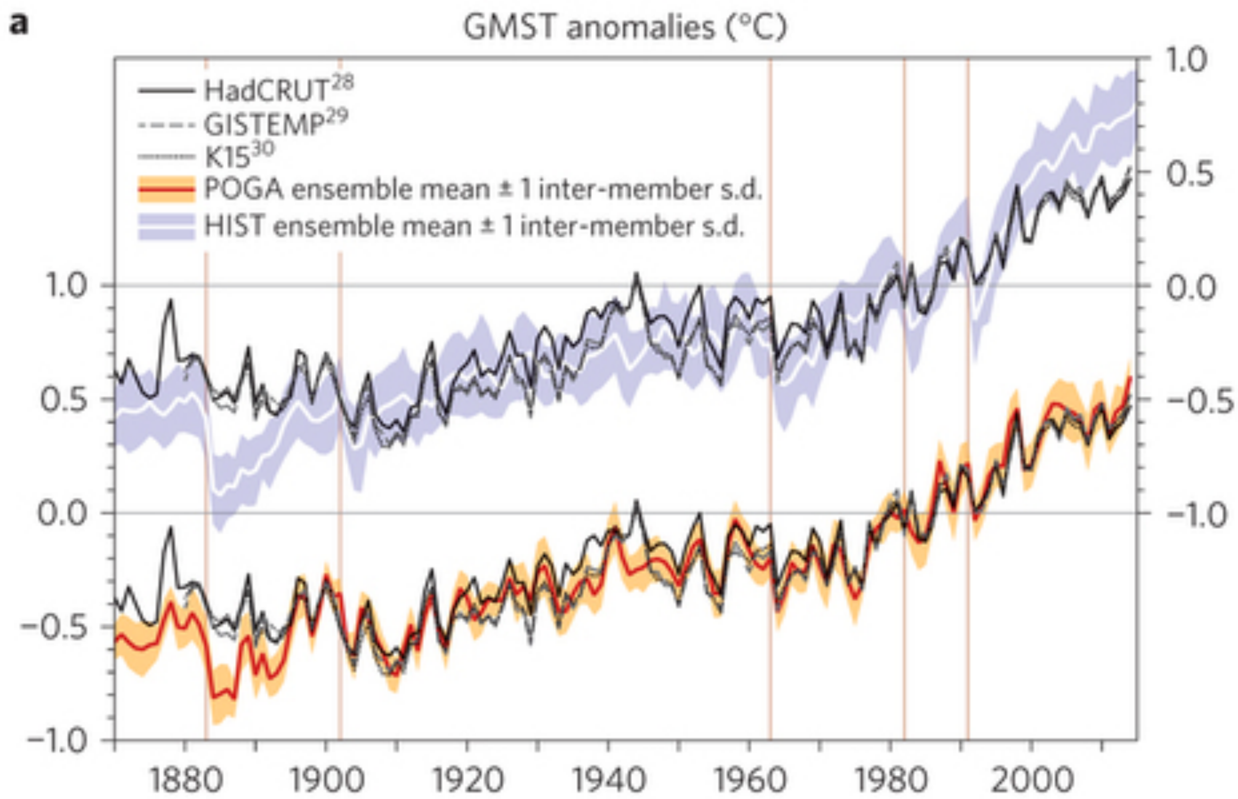
"Pacemaker" protocol

Global warming hiatus, ENSO response

Global Mean Surface Temperature Anomalies



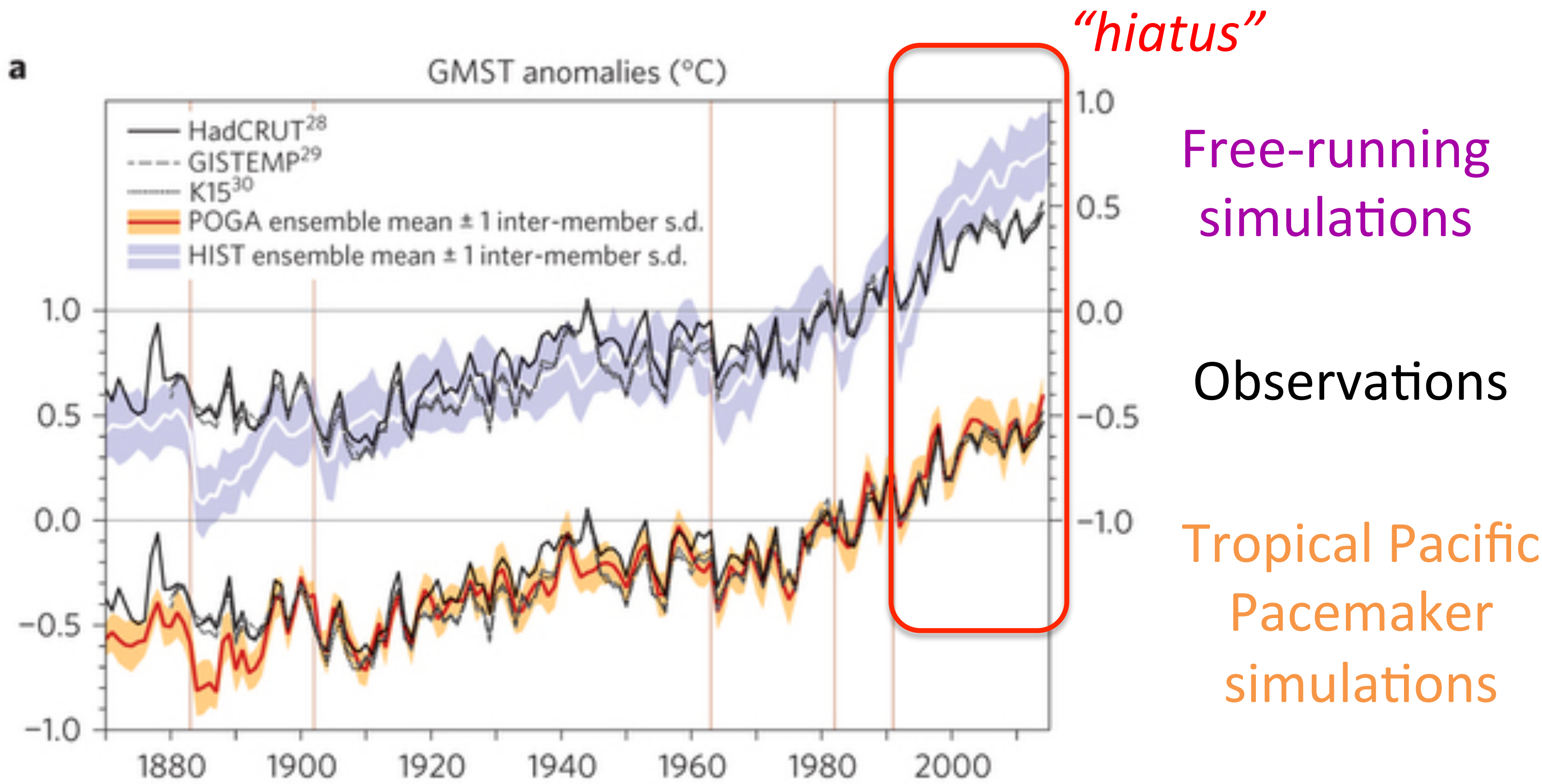
Free-running simulations

Observations

Tropical Pacific Pacemaker simulations

Kosaka and Xie, 2016: *Nature Geosciences*

Global Mean Surface Temperature Anomalies



Kosaka and Xie, 2016: *Nature Geosciences*

ENSO Response

El Nino minus La Nina Composite

14   12   1950-2014

Nino3.4
SST > 1 σ

Nino3.4
SST < -1 σ

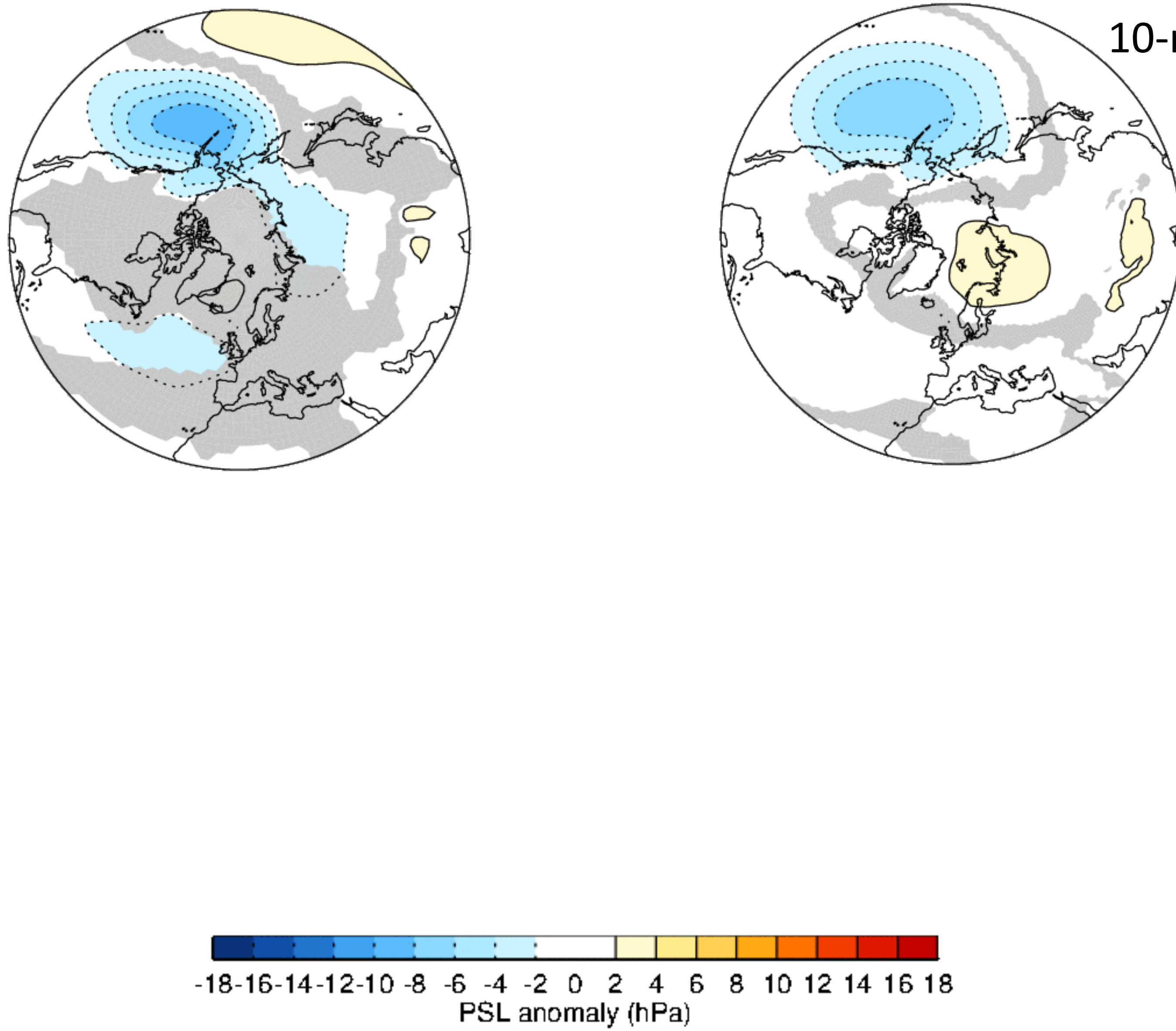
Deser and Simpson, in preparation

Winter SLP (hPa)

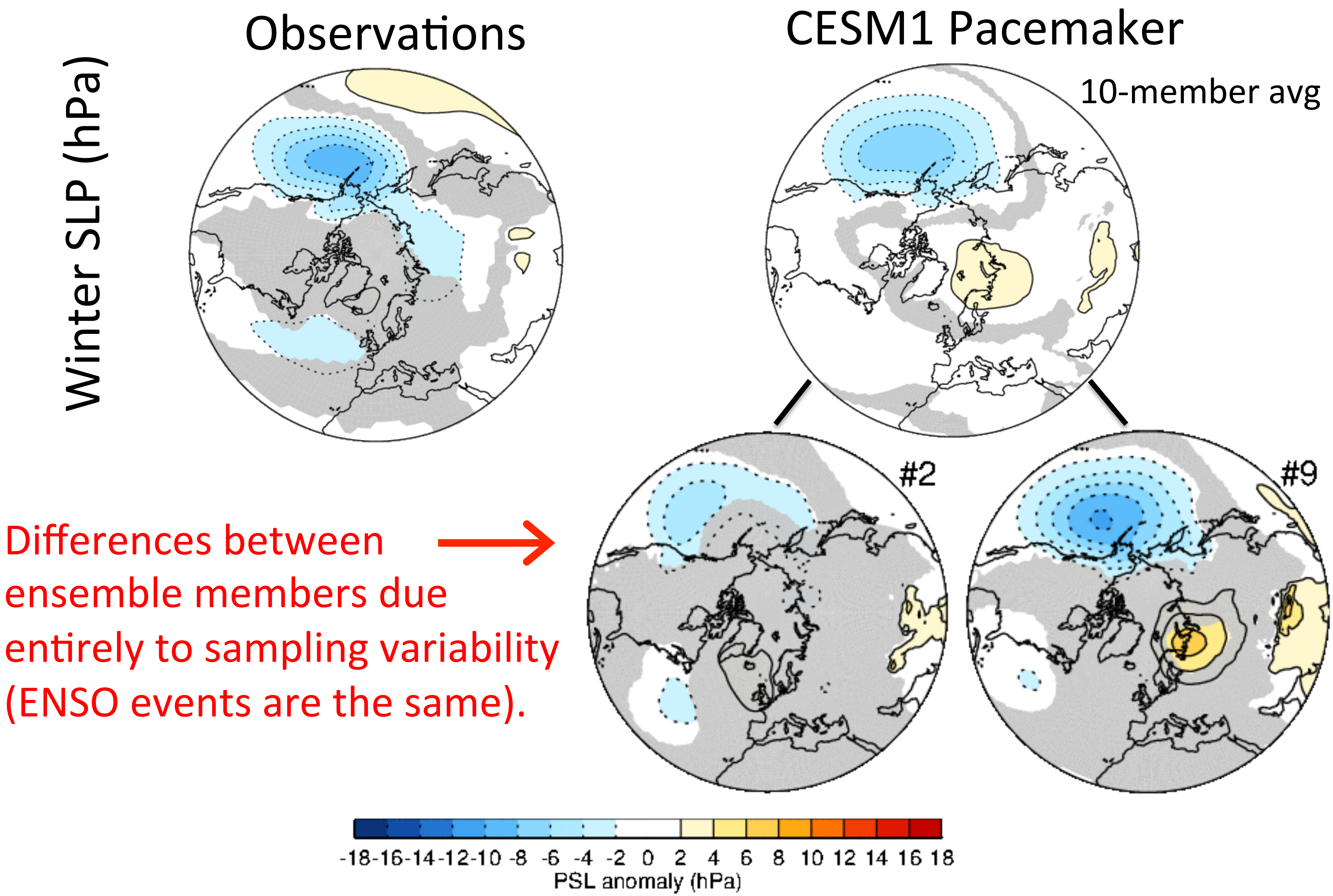
Observations

CESM1 Pacemaker

10-member avg



Gray shading: ENSO response not significant at the 5% level



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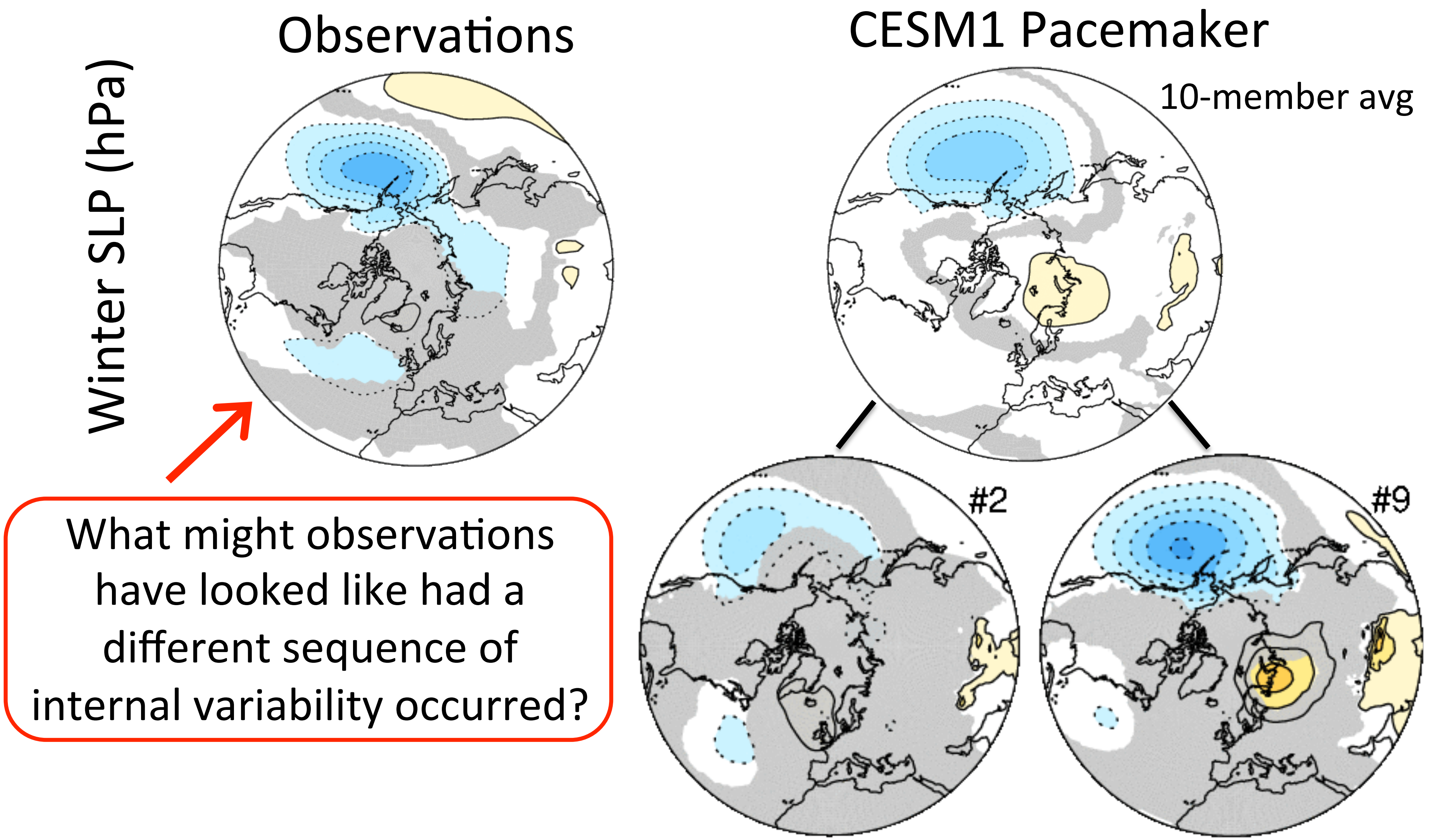
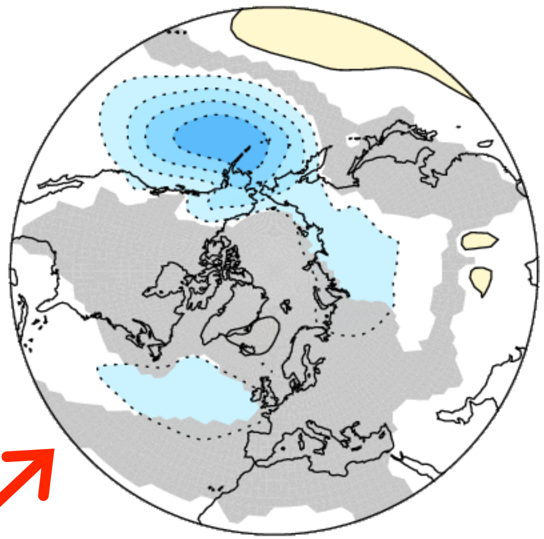

Observations
CESM1 Pacemaker
Winter SLP (hPa)
10-member avg
#2
#9
What might observations have looked like had a different sequence of internal variability occurred?

Winter SLP (hPa)

Observations



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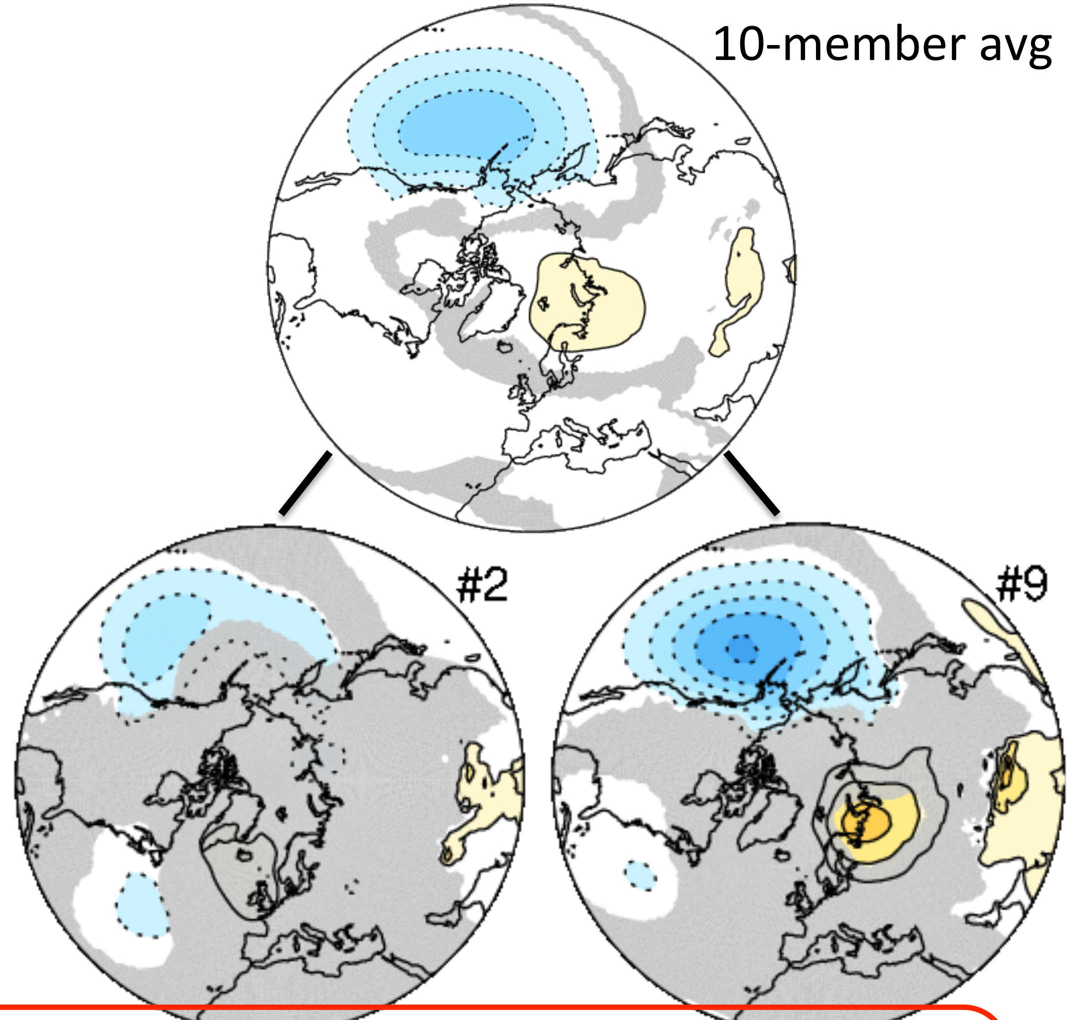
CESM1 Pacemaker



Is the model's response realistic?

Do the observed and modeled ENSO responses come from the same distribution?

Types of Models and Experiments

Hierarchy of Control Runs

Fully Coupled	Atmosphere-Mixed Layer Ocean	Atmosphere Only

- Atmospheric *vs.* Coupled Processes

NCAR UCAR | CGD's Climate Analysis Section
Climate Variability Diagnostics Package

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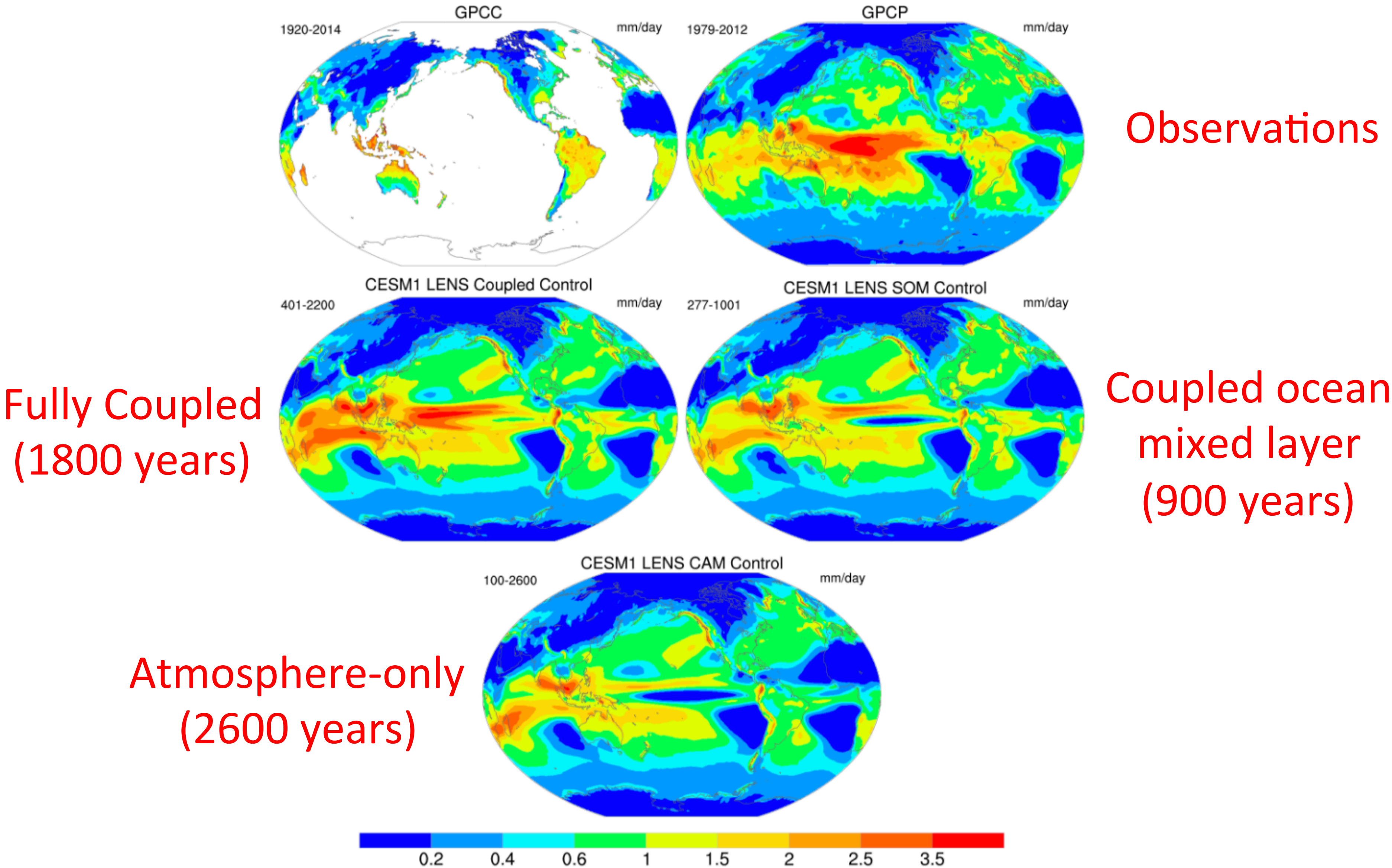
SIC SH	DJF	MAM	JJA	SON	Annual

//webext.cgd.ucar.edu/Multi-Case/CVDP_ex/CESM1-LENS-Controls/

Precipitation Standard Deviation (DJF)



Types of Models and Experiments

Free-running coupled climate models	Constrained climate models	Model hierarchy

All have utility.

The most appropriate one depends on the questions you are asking.

Extra

The CESM Large Ensemble Project

A Community Resource for Studying Climate Change in the Presence of Internal Climate Variability

The CESM Large Ensemble Project

www2.cesm.ucar.edu/models/experiments/LENS

THE COMMUNITY EARTH SYSTEM MODEL (CESM) LARGE ENSEMBLE PROJECT

A Community Resource for Studying Climate Change in the Presence of Internal Climate Variability

BY J. E. KAY, C. DESER, A. PHILLIPS, A. MAI, C. HANNAY, G. STRAND, J. M. ARBLASTER, S. C. BATES, G. DANABASOGLU, J. EDWARDS, M. HOLLAND, P. KUSHNER, J.-F. LAMARQUE, D. LAWRENCE, K. LINDSAY, A. MIDDLETON, E. MUNOZ, R. NEALE, K. OLESON, L. POLVANI, AND M. VERTENSTEIN

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.

BAMS
doi:10.1175/BAMS-D-13-00255.1

LENS COMMUNITY PROJECT

- Community Project Background
- Instructions for Reproducing - Protocol and Forcing Information
- Diagnostics
- Data Sets Available to the Community
- Support for the Community
- Publications
- On-going Project Descriptions
- Known Issues

CESM-LE Experimental Design

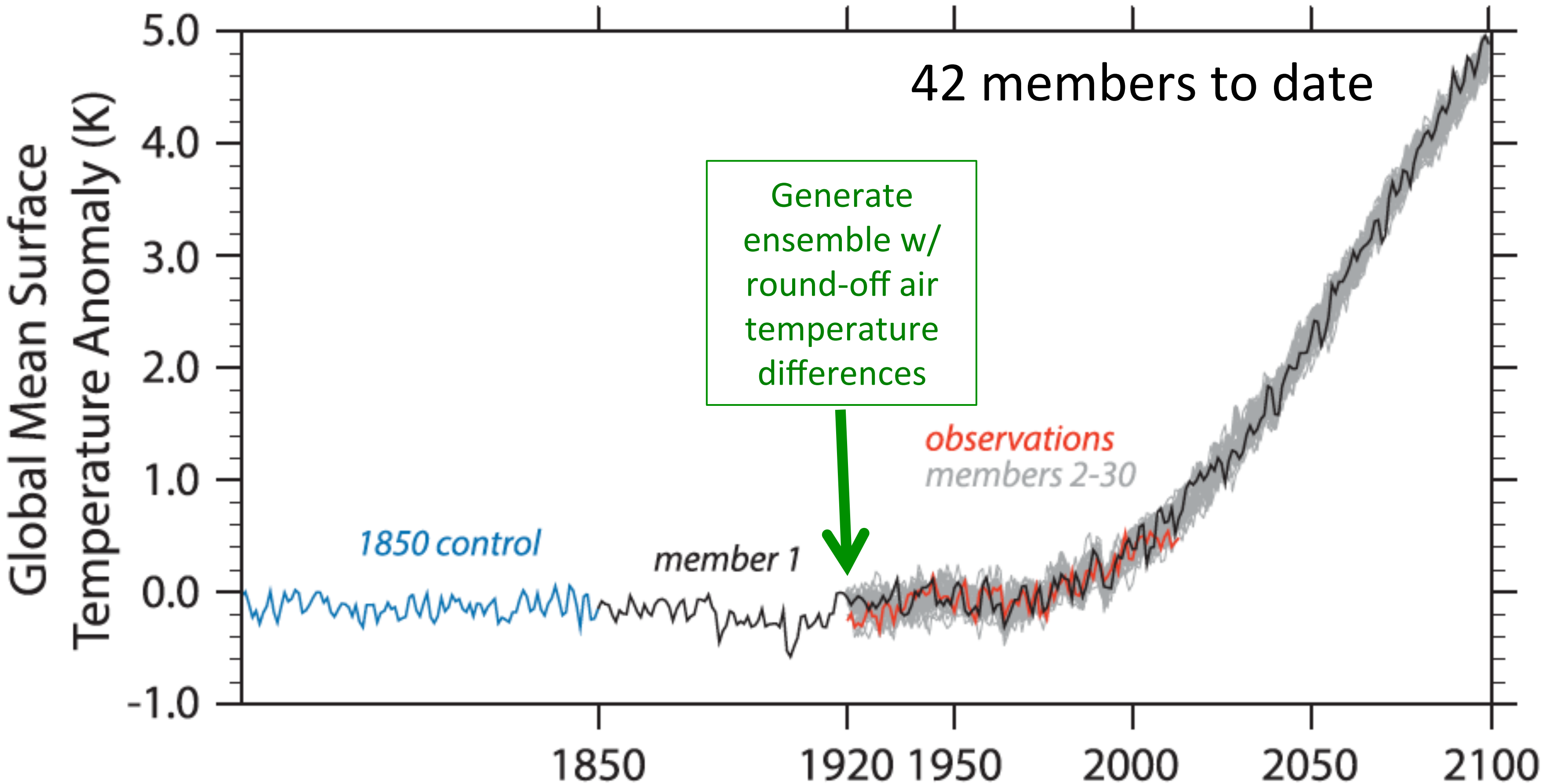


Fig. 2. Global surface temperature anomaly (1961–90 base period) for the 1850 control, individual ensemble members, and observations (HadCRUT4; Morice et al. 2012).

Figure from doi:10.1175/BAMS-D-13-00255.1

First Days of the CESM-LE:
Deterministic Weather to Chaotic Climate

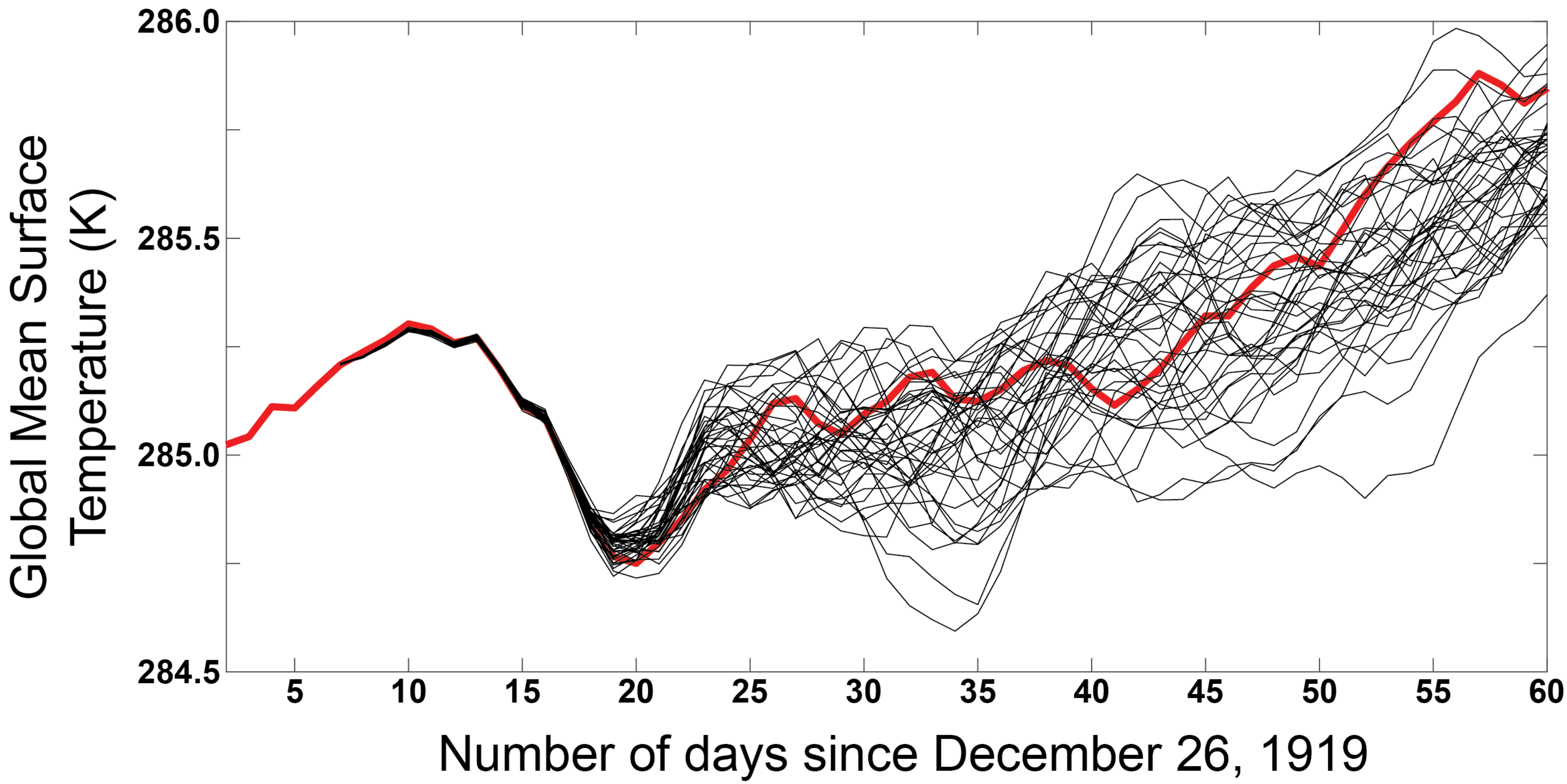


Figure from Vineel Yettella (University of Colorado)

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