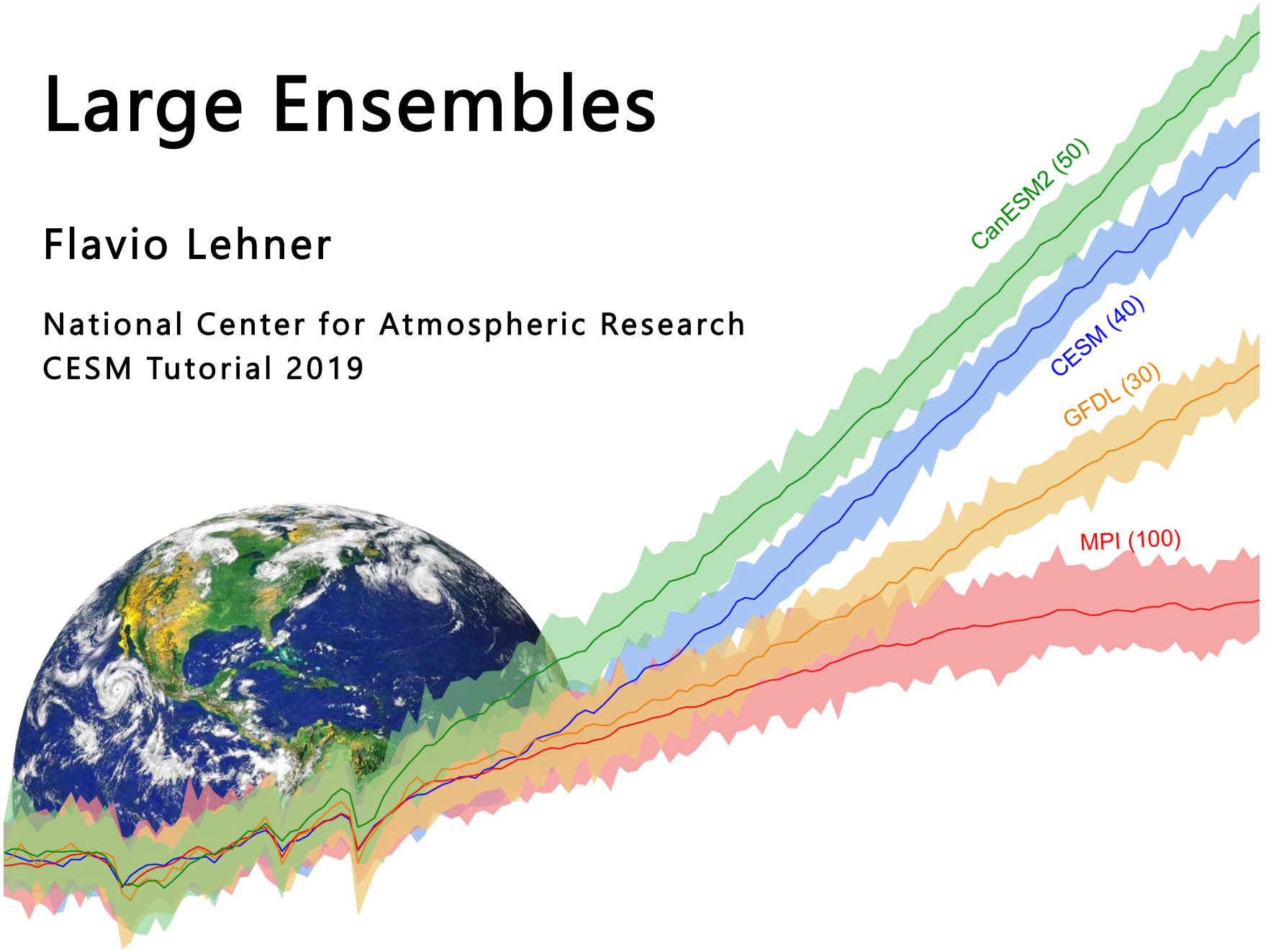
Large Ensembles

Flavio Lehner

National Center for Atmospheric Research
CESM Tutorial 2019



Learning goals

- What is an Ensemble? What is a *Large* Ensemble?
- What can Large Ensembles be used for?
- Large Ensemble resources

What is an Ensemble?

Ensemble:

What is an Ensemble?

Ensemble: a group of items viewed as a whole rather than individually

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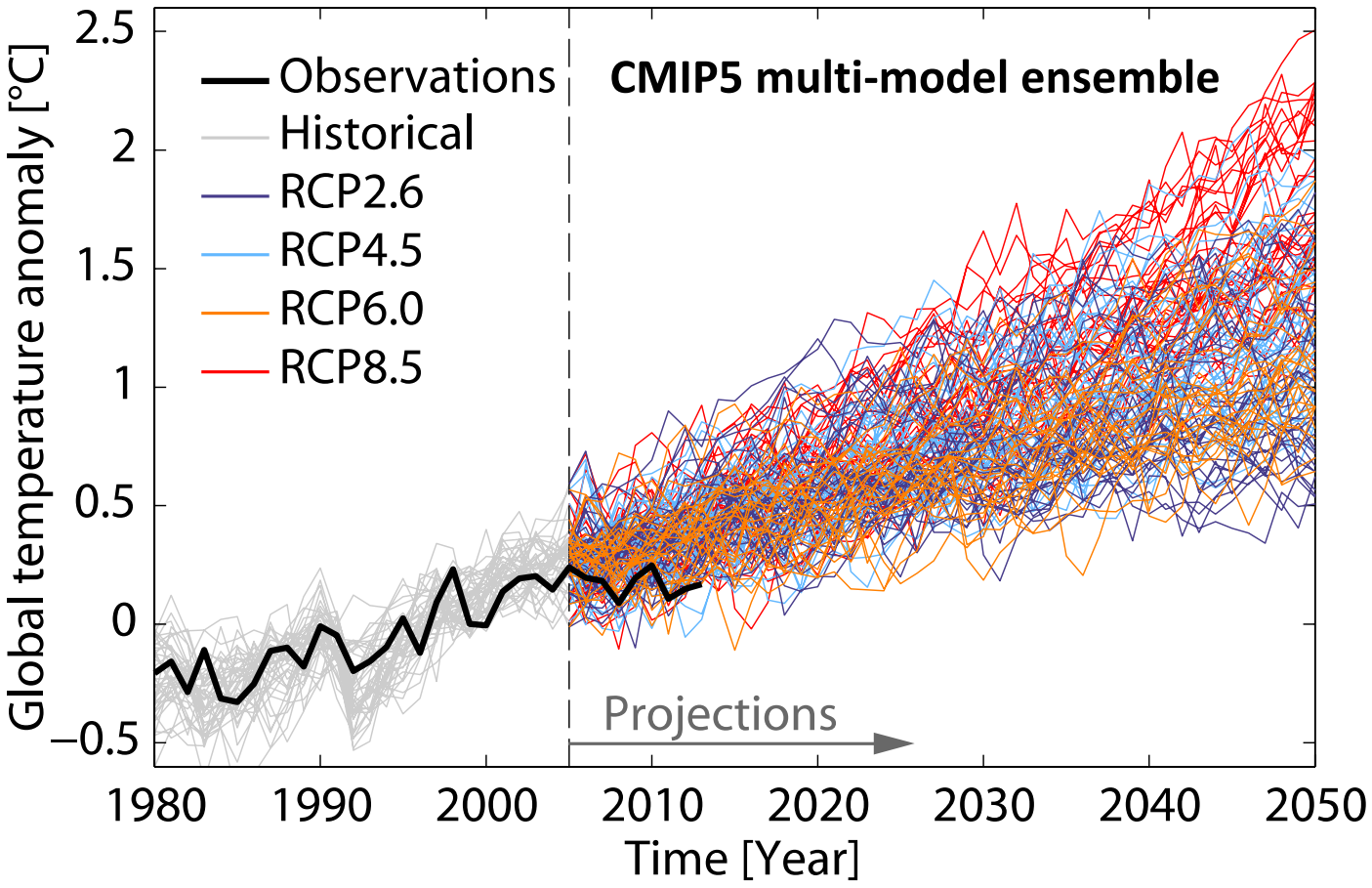
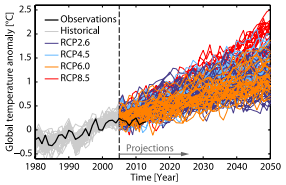


What is a Large Ensemble?

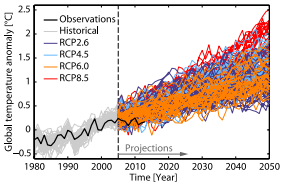
Ensemble



What is a Large Ensemble?

Large Ensemble

>10 runs



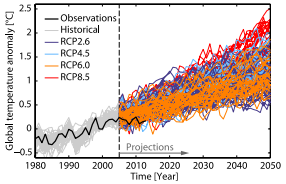
What is a Large Ensemble?

Single Model

CESM2

Large Ensemble

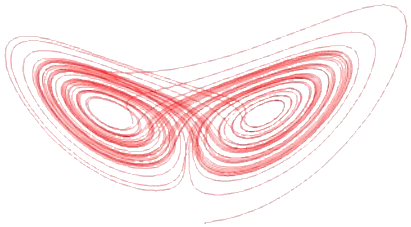
>10 runs



What is a Large Ensemble?

Single Model Initial-Condition Large Ensemble

CESM2



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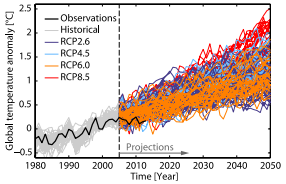
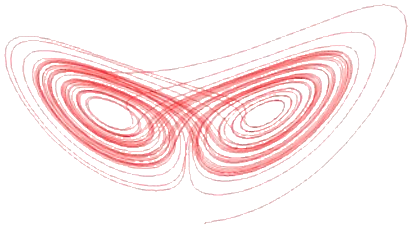


What is a Large Ensemble?

Single Model Initial-Condition Large Ensemble (SMILE)

CESM2



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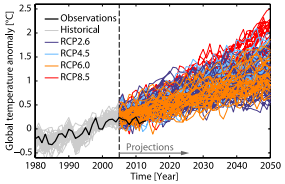

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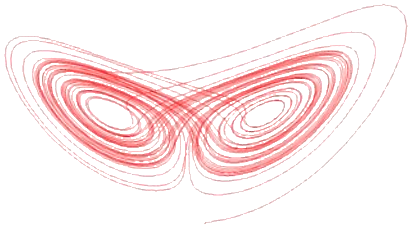

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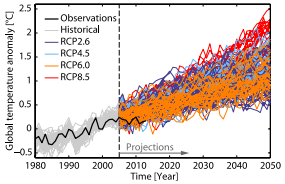

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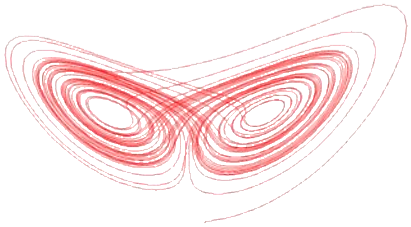

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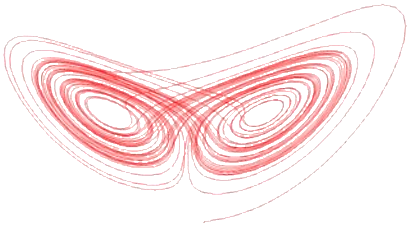

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<u>Single Model Initial-Condition</u> Large Ensemble (SMILE)

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Lorenz equations

$$\frac{\mathrm{d}x}{\mathrm{d}t} = \sigma(y - x),$$

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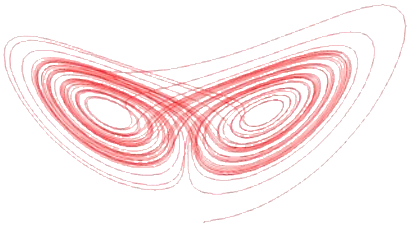

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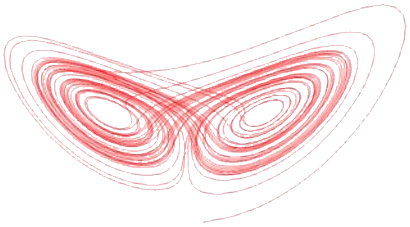

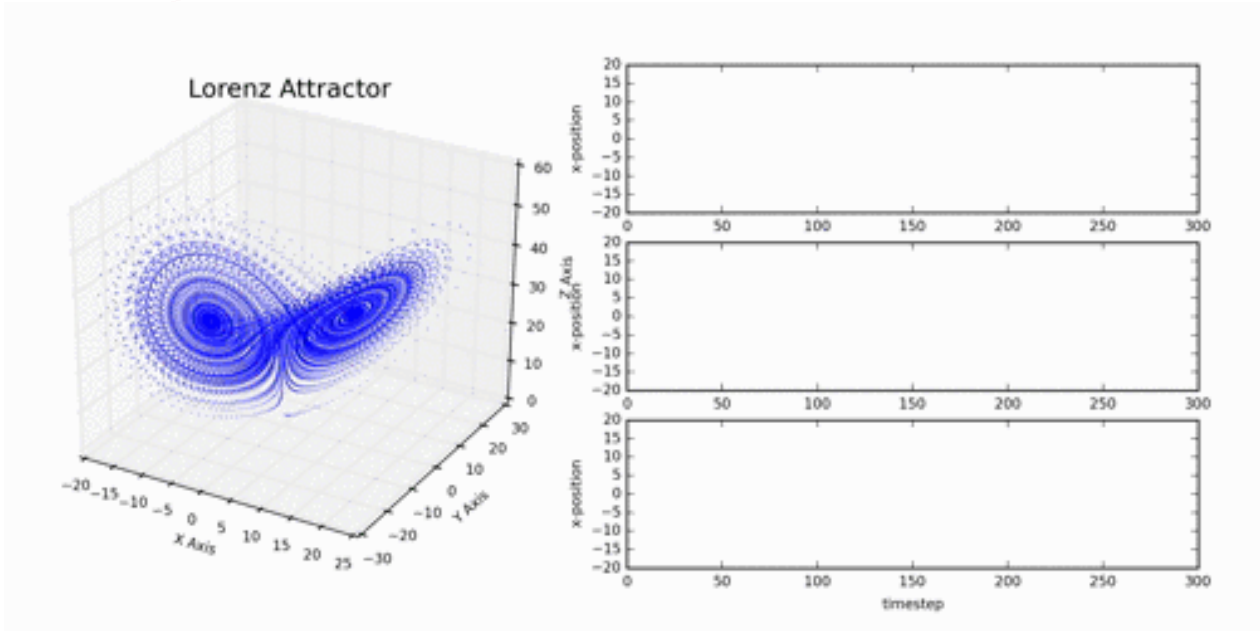

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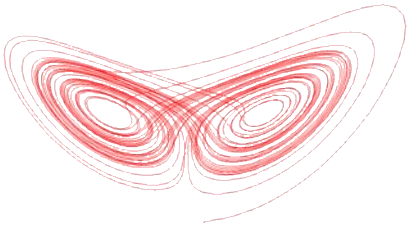

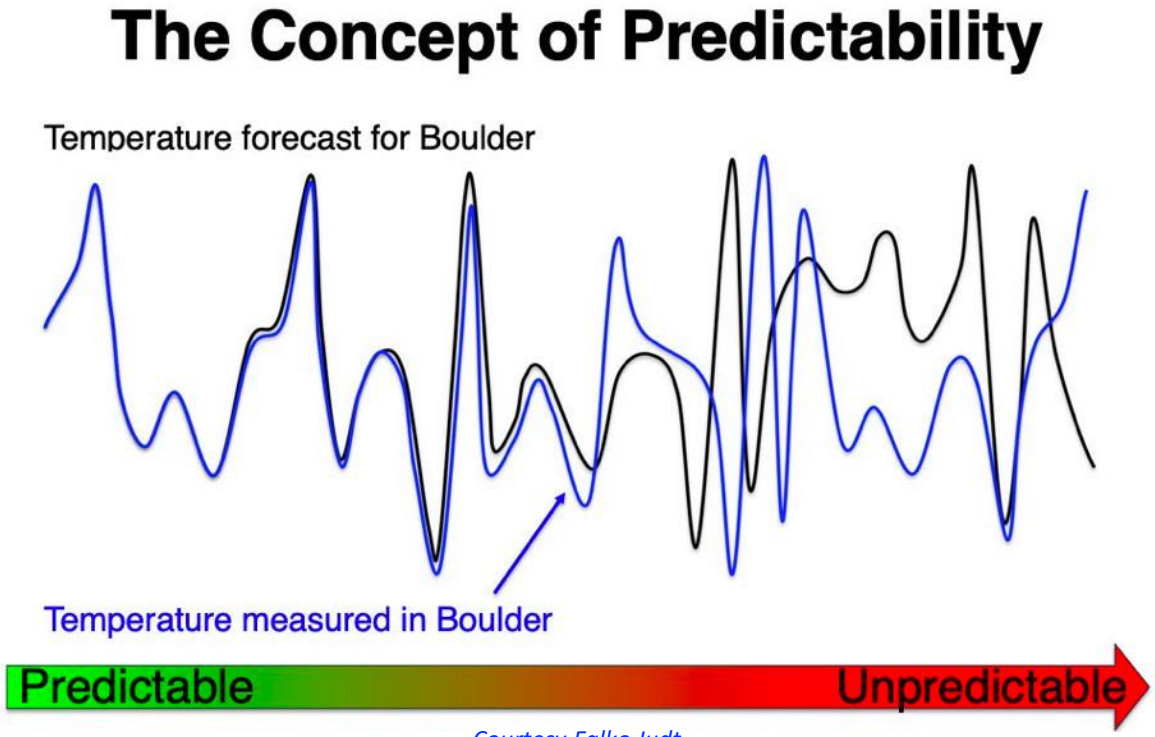

Courtesy Falko Judt

What is a Large Ensemble?

Single Model Initial-Condition Large Ensemble (SMILE)

CESM2

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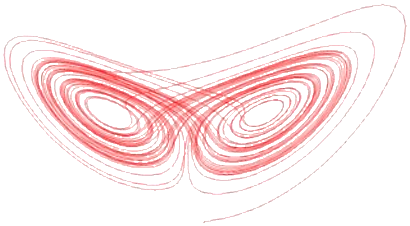

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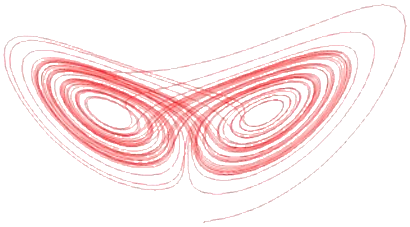

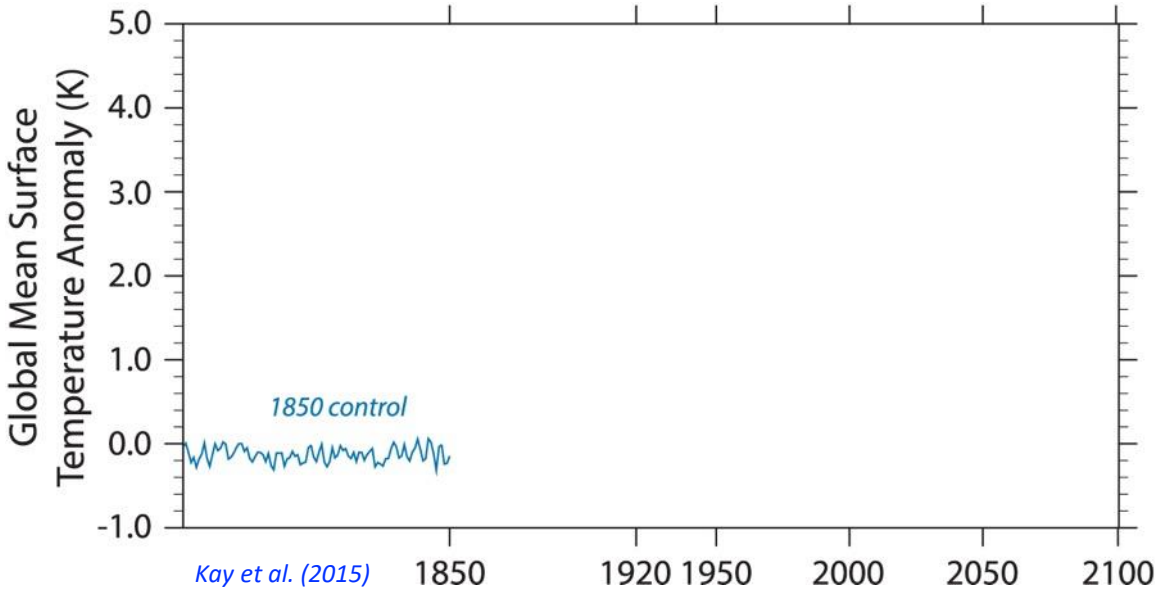

Kay et al. (2015)

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CESM2

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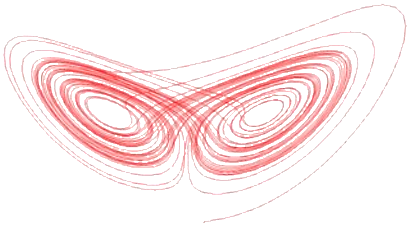

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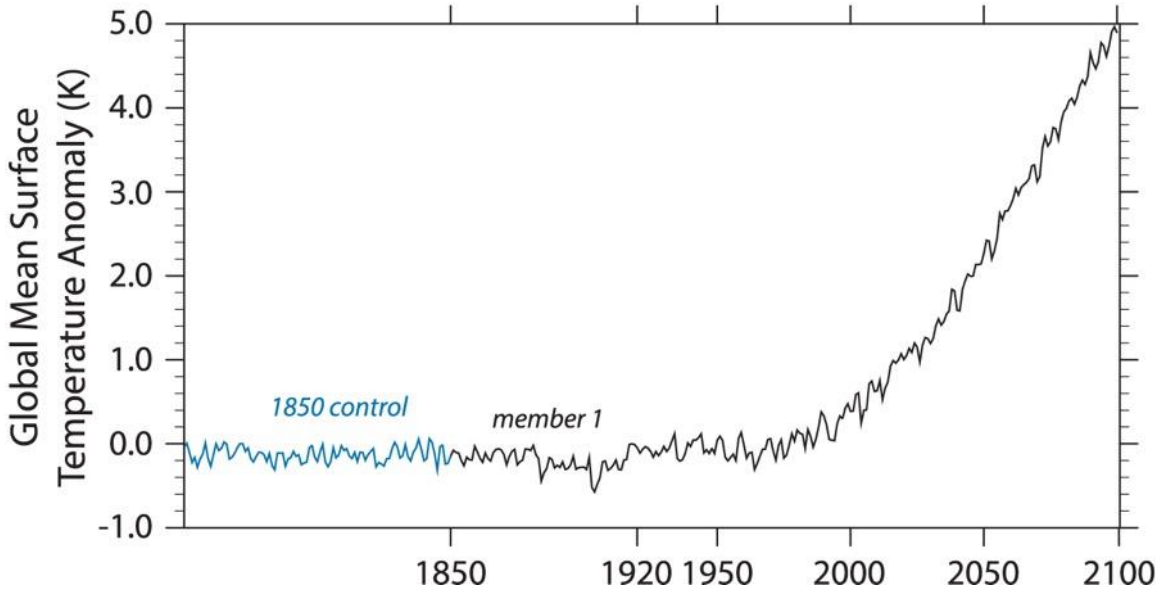

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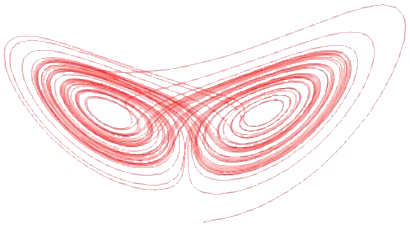

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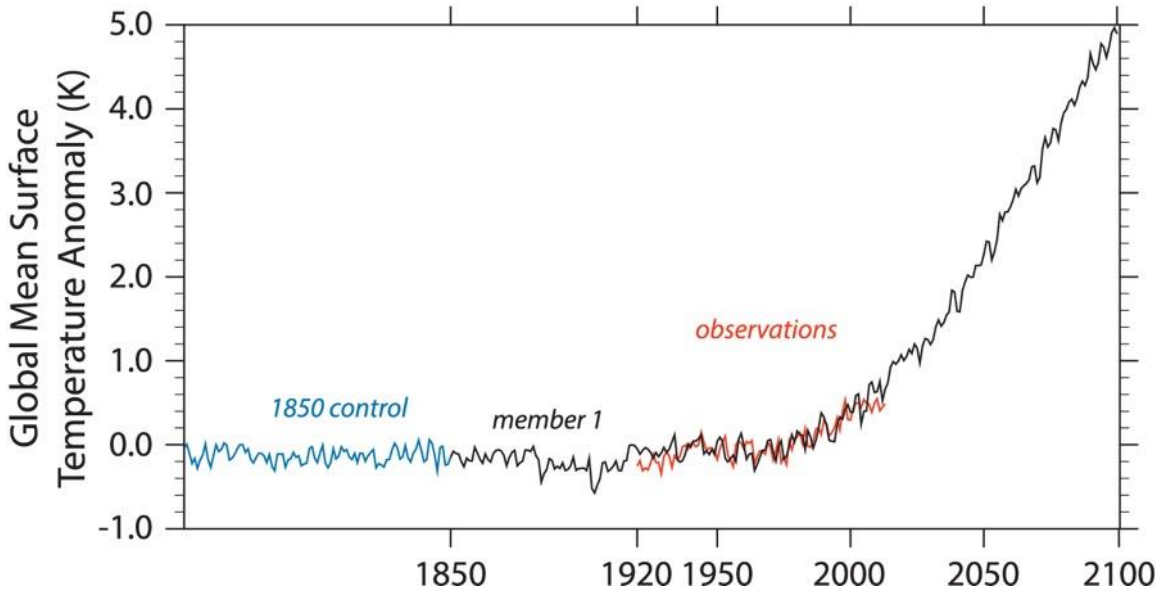

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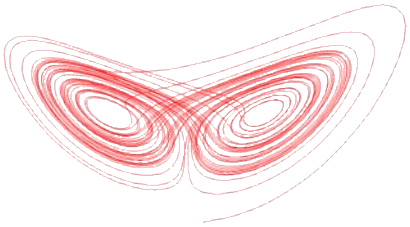

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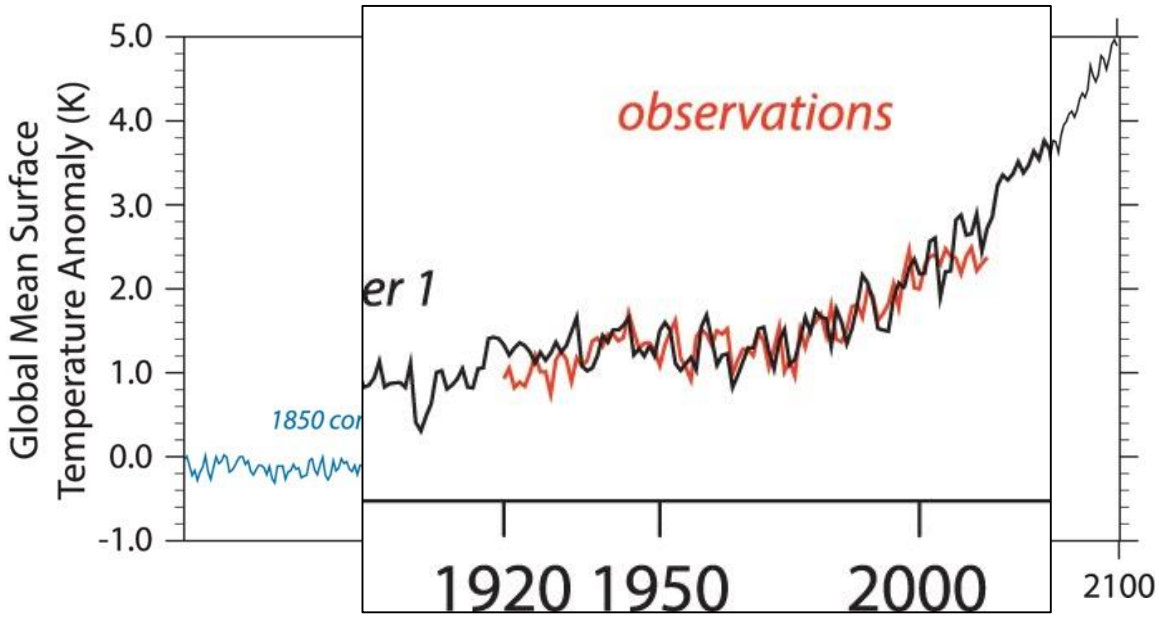

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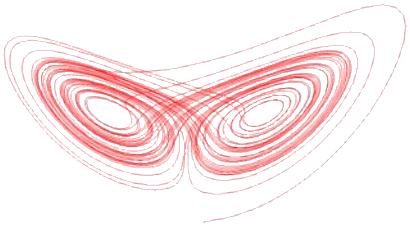

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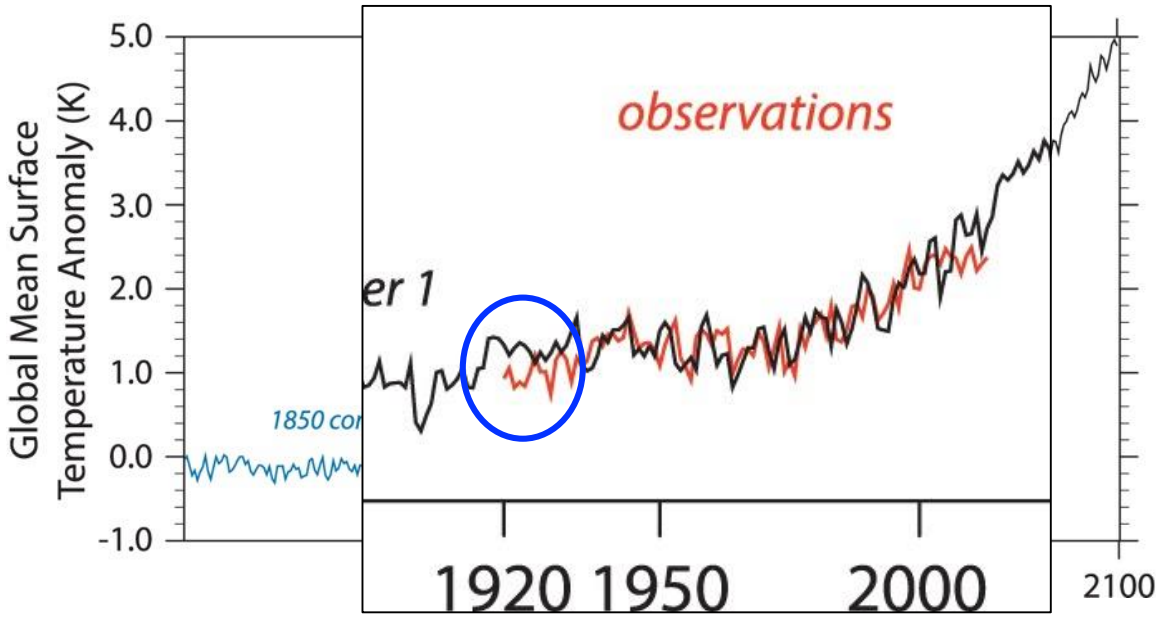

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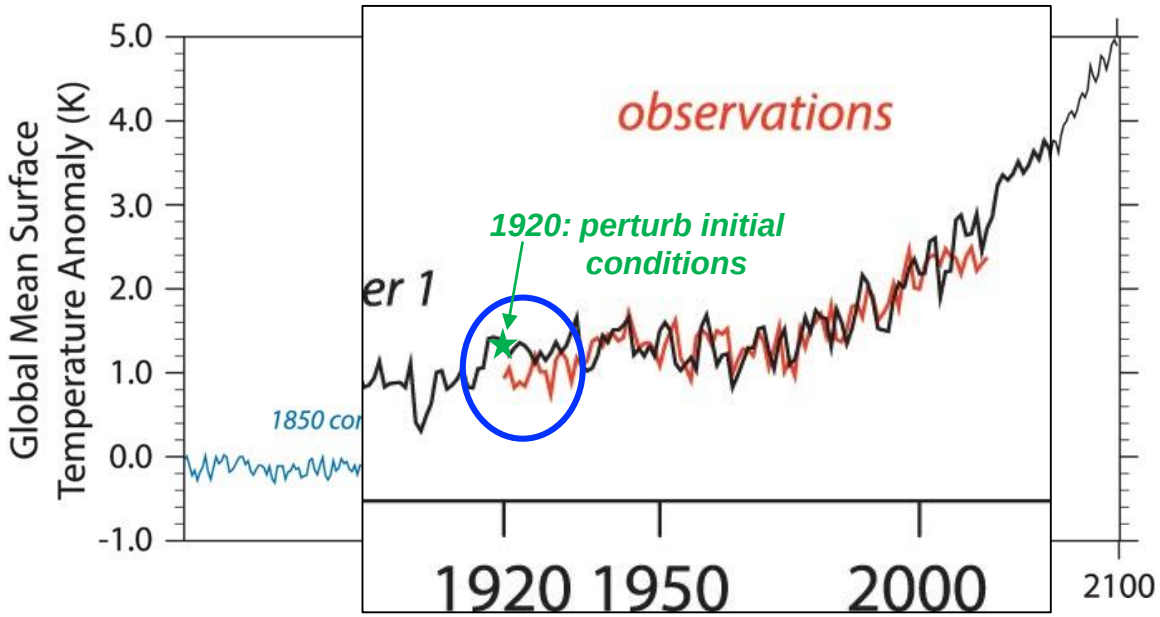

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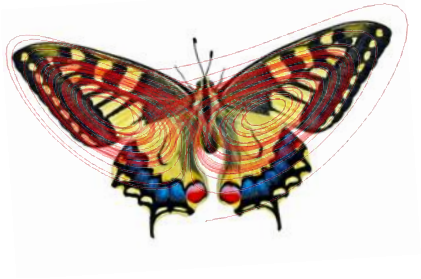

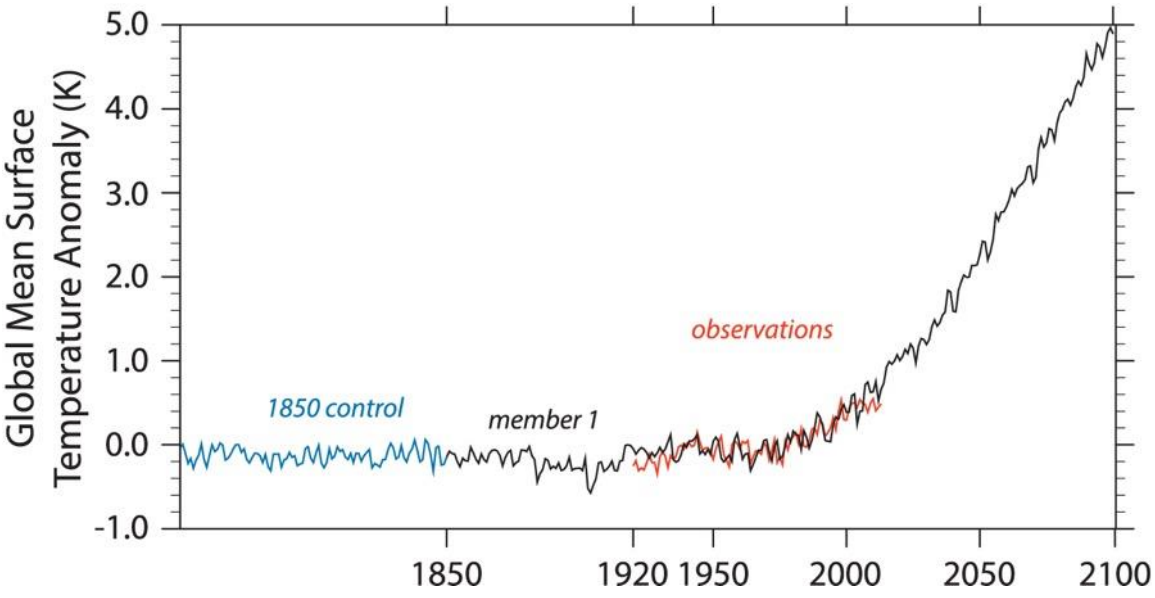

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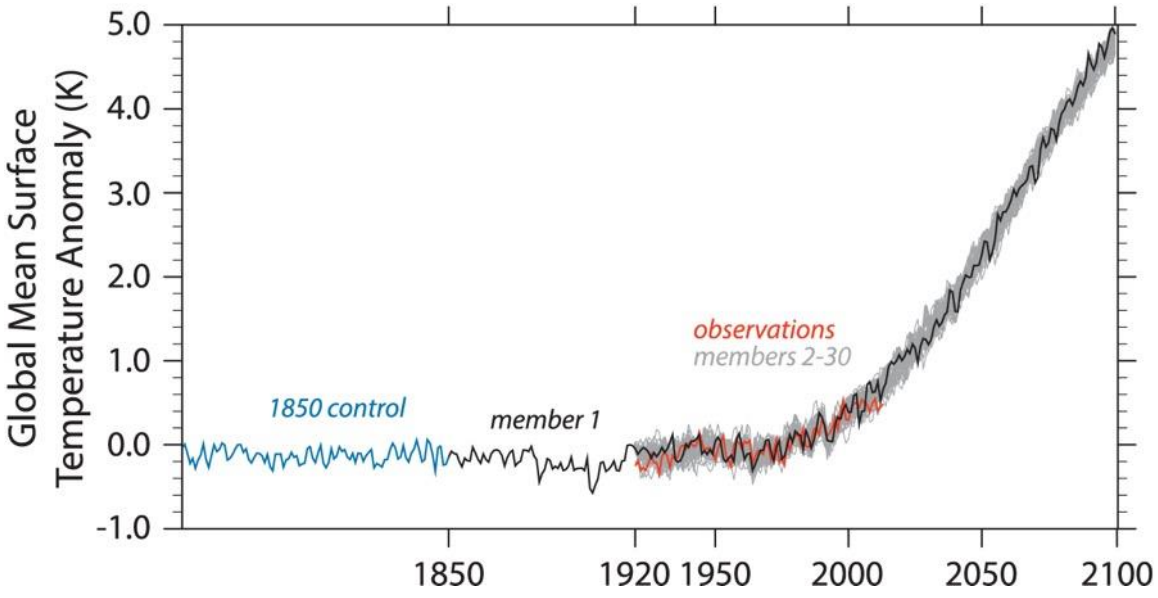

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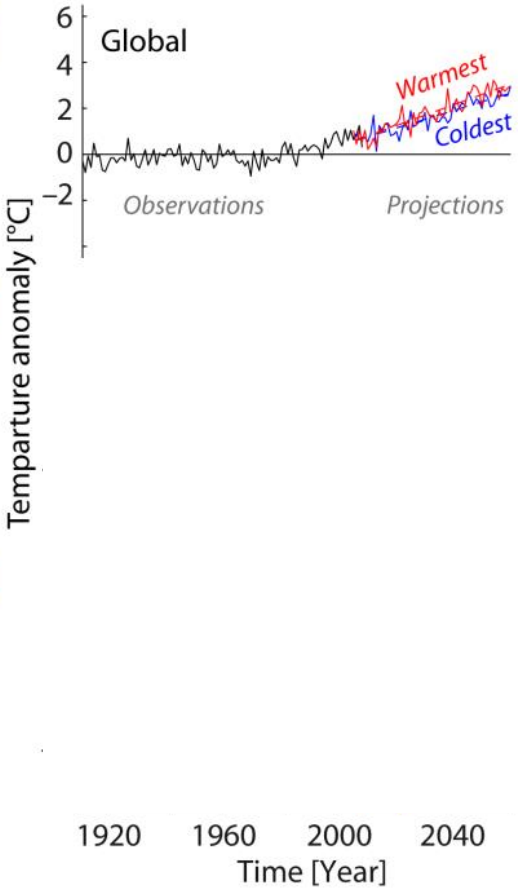

After Deser et al. (2012)

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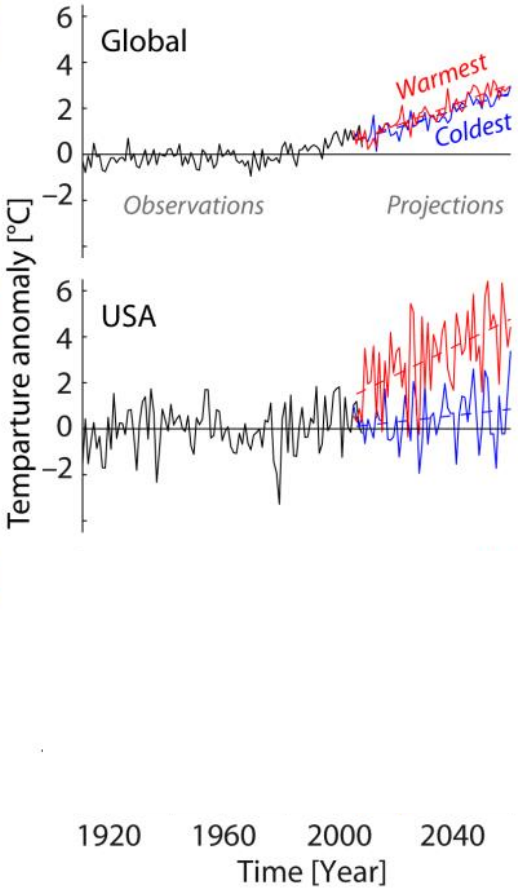

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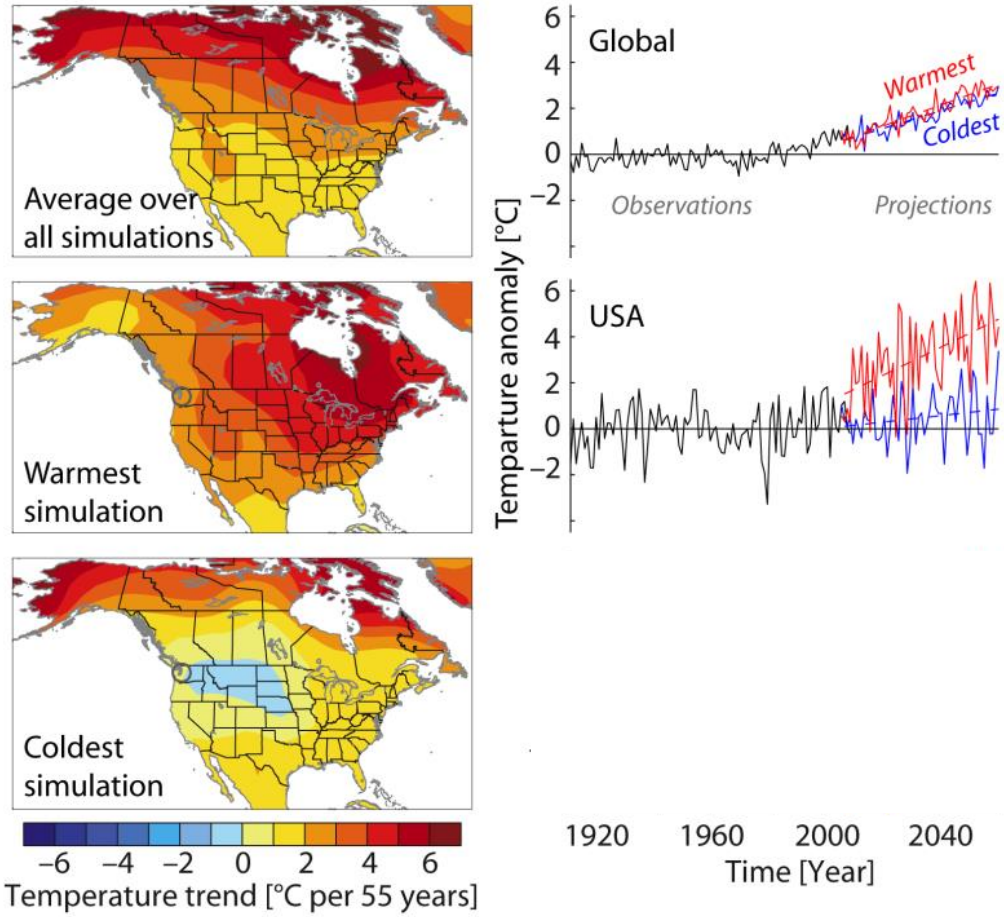

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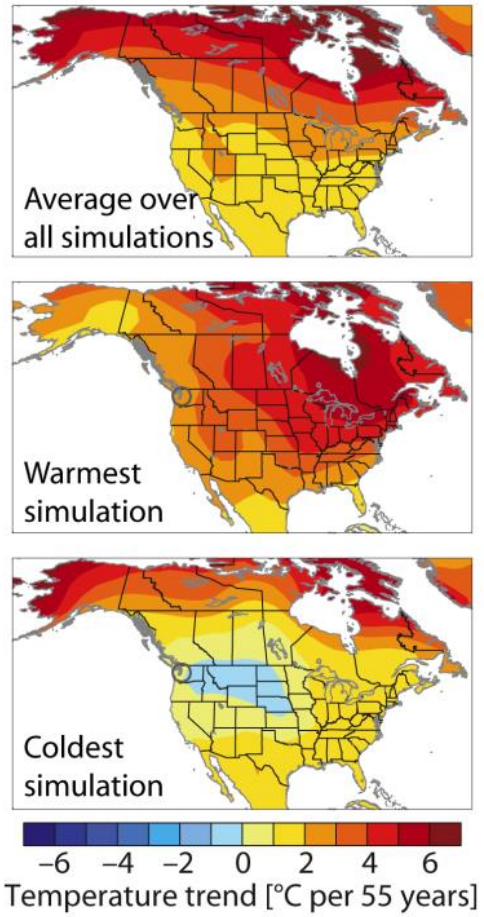

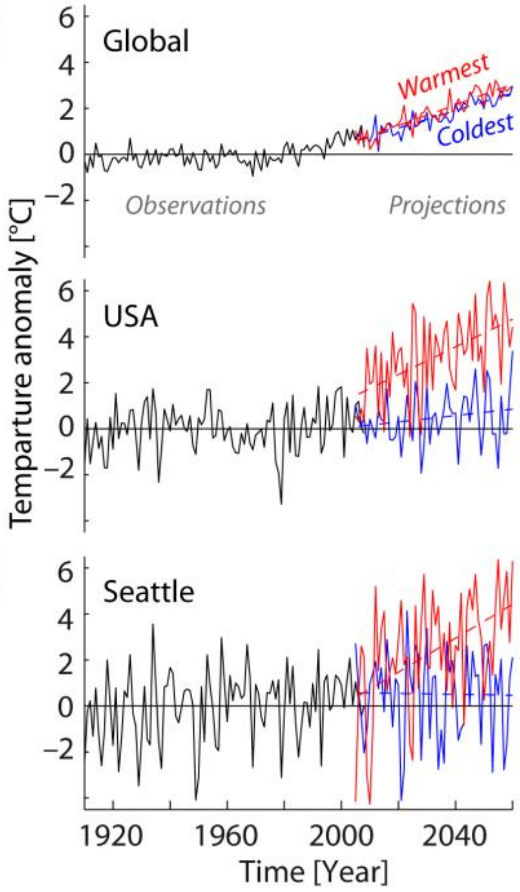

What can Large Ensembles be used for?

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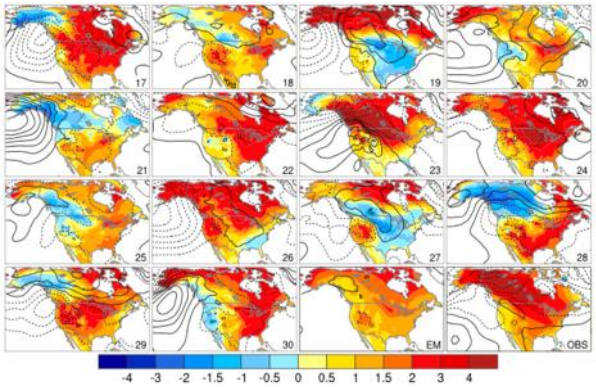
Interpret the observational record



Deser et al. (2016)

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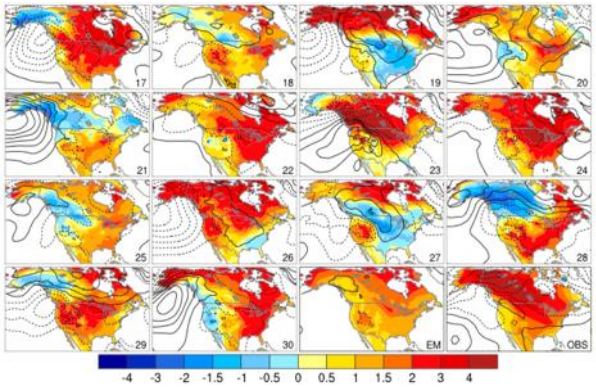
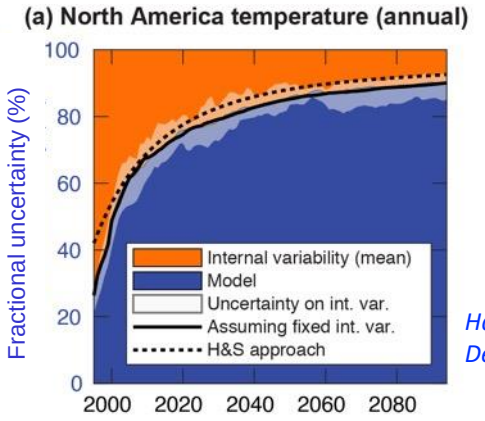


Deser et al. (2016)

Assess forced response and partition uncertainty



Hawkins & Sutton (2009)
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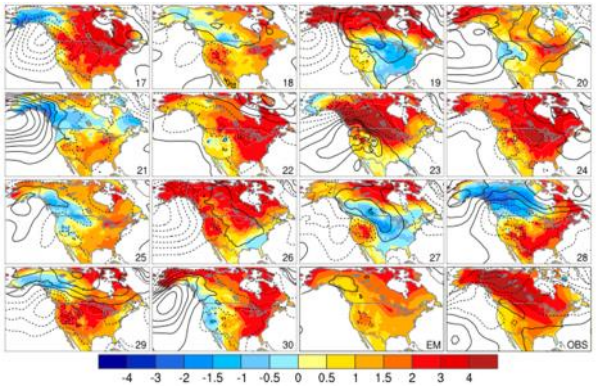

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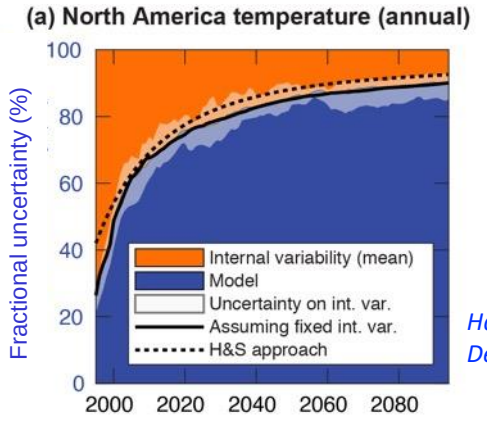

Hawkins & Sutton (2009)
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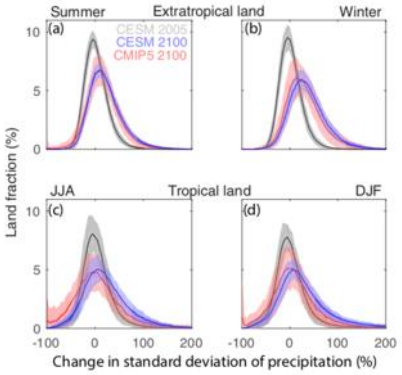
Study internal variability



Pendergrass et al. (2017)

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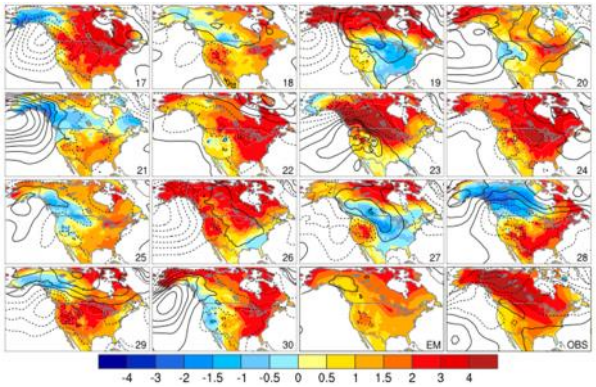

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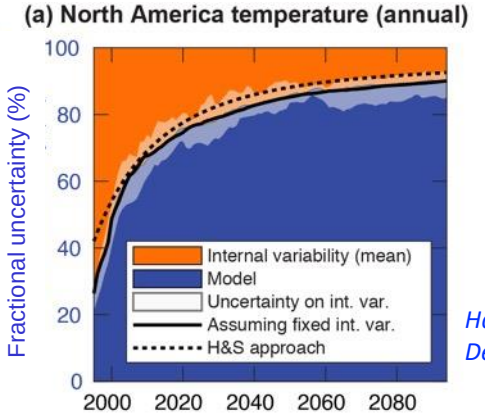

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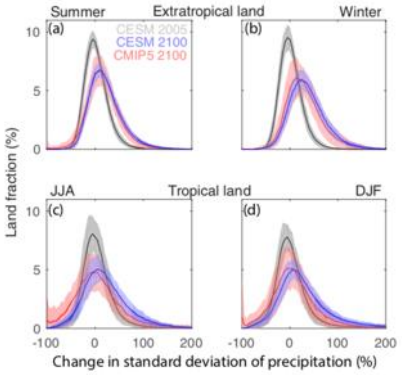

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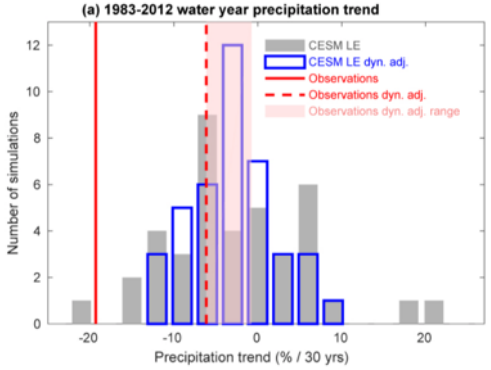
Test new methods



Lehner et al. (2018)

Large Ensemble resources

CESM1 Large Ensemble (CESM2 Large Ensemble with 100 ensemble members planned)

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Multi-Model Large Ensemble Archive (MMLEA)**:**

- Set of variables from different CMIP5-class LEs
- CMORized and made publicly available (CDG and Cheyenne)
- Includes Observational-LE for temperature and precipitation
- Goal of facilitating model comparison and evaluation - accelerating scientific discovery
- Idea for it to grow with community input (more variables, new LEs, new Observational-LEs, etc.)

Modeling Center	Model Version	Model Resolution (atm/ocn)	Years	Initialization Method	Number of Members		
CCCma	CanESM2	~2.8°x2.8°/~1.4°x0.9°	1950-2100	Macro and Micro	50		
CSIRO	MK3.6	~1.9°x1.9°/~1.9°x1.0°	1850-2100	Macro	30	rcp85	(2013)
GFDL	ESM2M	~2.0°x2.5°/~1.0°x0.9°	1950-2100	Macro	30	historical, rcp85	Rodgers et al. (2015)
GFDL	CM3	~2.0°x2.5°/~1.0°x0.9°	1920-2100	Micro	20	historical, rcp85	Sun et al. (2018)
MPI	MPI-ESM-LR	~1.9°x1.9°/nominal 1.5°	1850-2100	Macro	100	historical, rcp26, rcp45, rcp85	Maher et al. (2019)
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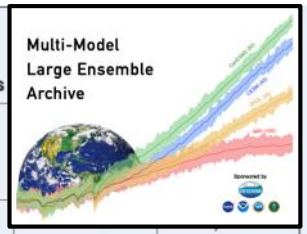

www.cesm.ucar.edu/projects/community-projects/MMLEA/

Large Ensemble resources

CESM1 Large Ensemble (CESM2 Large Ensemble with 100 ensemble members planned)

Multi-Model Large Ensemble Archive (MMLEA)**:**

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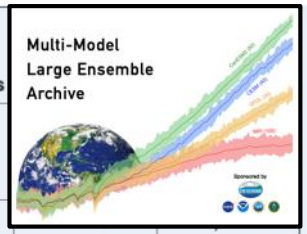

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SMILE email list:
https://listserv.gwdg.de/mailman/listinfo/smile

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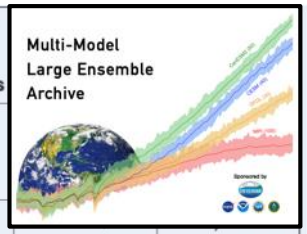

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SMILE email list:
https://listserv.gwdg.de/mailman/listinfo/smile

Thanks!
flehner@ucar.edu

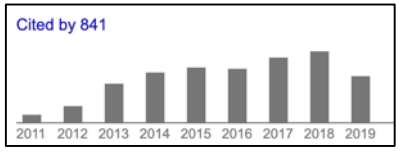
Supplementary slides

What is a Large Ensemble?

Clim Dyn (2012) 38:527–546
DOI 10.1007/s00382-010-0977-x

Uncertainty in climate change projections: the role of internal variability

Clara Deser · Adam Phillips · Vincent Bourdette · Haiyan Teng

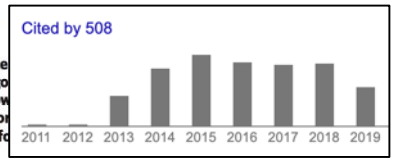


nature climate change
PERSPECTIVE
PUBLISHED ONLY: 26 OCTOBER 2012 | DOI: 10.1038/NCLIMATE1562

Communication of the role of natural variability in future North American climate

Clara Deser[1]*, Reto Knutti[2], Susan Solomon[3] and Adam S. Phillips[1]

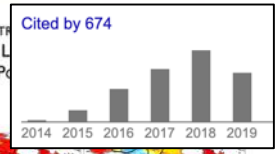
As climate models improve, decision-makers' expectations for accurate climate
variability, however, poses inherent limits to climate predictability and the related go
illustrated here for North America. Other locations with low natural variability show
pogenic forcing can be more readily identified, even on small scales. We call for a mo
cymakers and the public to improve communication and avoid raising expectations fo

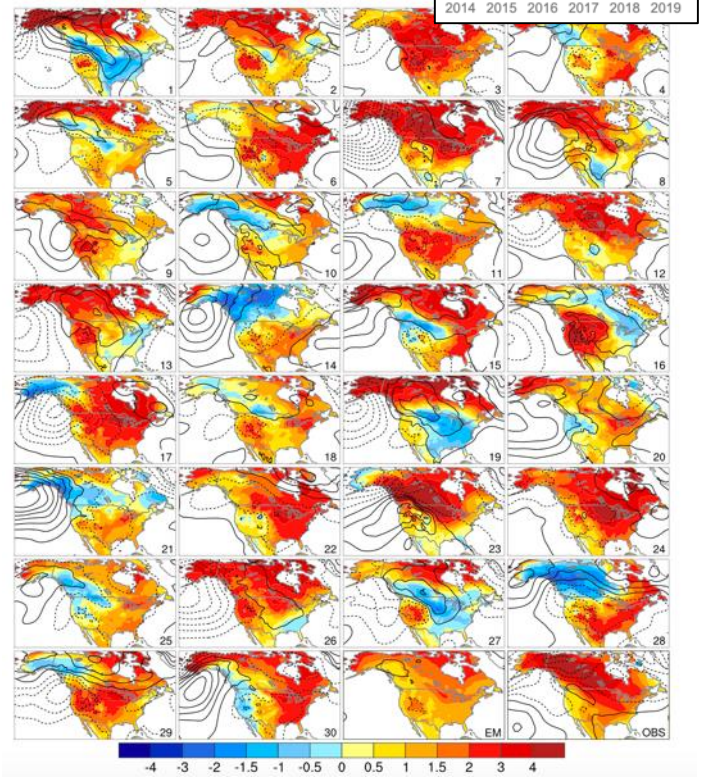


THE COMMUNITY EARTH SYSTEM MODEL (CESM) LARGE ENSEMBLE PROJECT

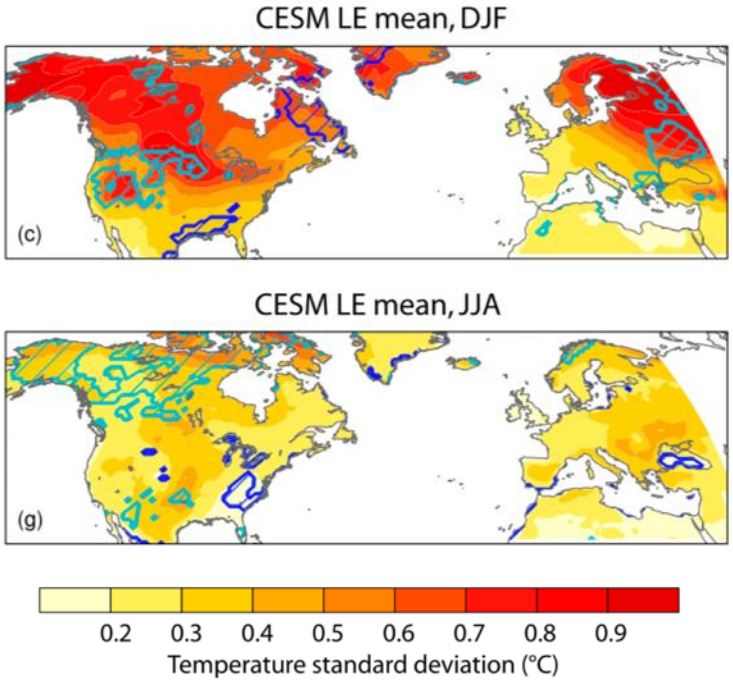
A Community Resource for Studying Climate Change in the Presence of Internal Climate Variability

BY J. E. KAY, C. DESER, A. PHILLIPS, A. MAI, C. HANNAY, G. STR
G. DANABASOGLU, J. EDWARDS, M. HOLLAND, P. KUSHNER, J.-F. L
A. MIDDLETON, E. MUNOZ, R. NEALE, K. OLESON, L. PO





Limitations of a single LE

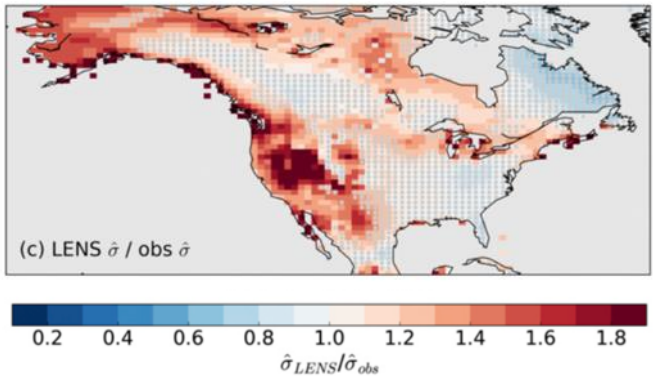


Model biases in decadal variability

"…indicating that the forced warming signal emerges earlier in observations than suggested by models."

Lehner at al. (2017)

CESM DJF temperature trends



Model biases in 50-year trends, assessed using an observational LE

"…[it] is easier to detect the historical climate change signal in observations than in any given member of LENS."

McKinnon at al. (2017)

Beyond a single LE

Large Ensemble Working Group

US CLIVAR Working Group on Large Ensembles

"Foster exchange of ideas relevant to LEs across disciplines (i.e., atmosphere, ocean, land, biogeochemistry)"

usclivar.org/working-groups/large-ensemble-working-group

Creation of a Multi-Model Large Ensemble Archive (MMLEA)**:**

- Set of variables from different CMIP5-class LEs
- CMORized and made publicly available (CDG and Cheyenne)
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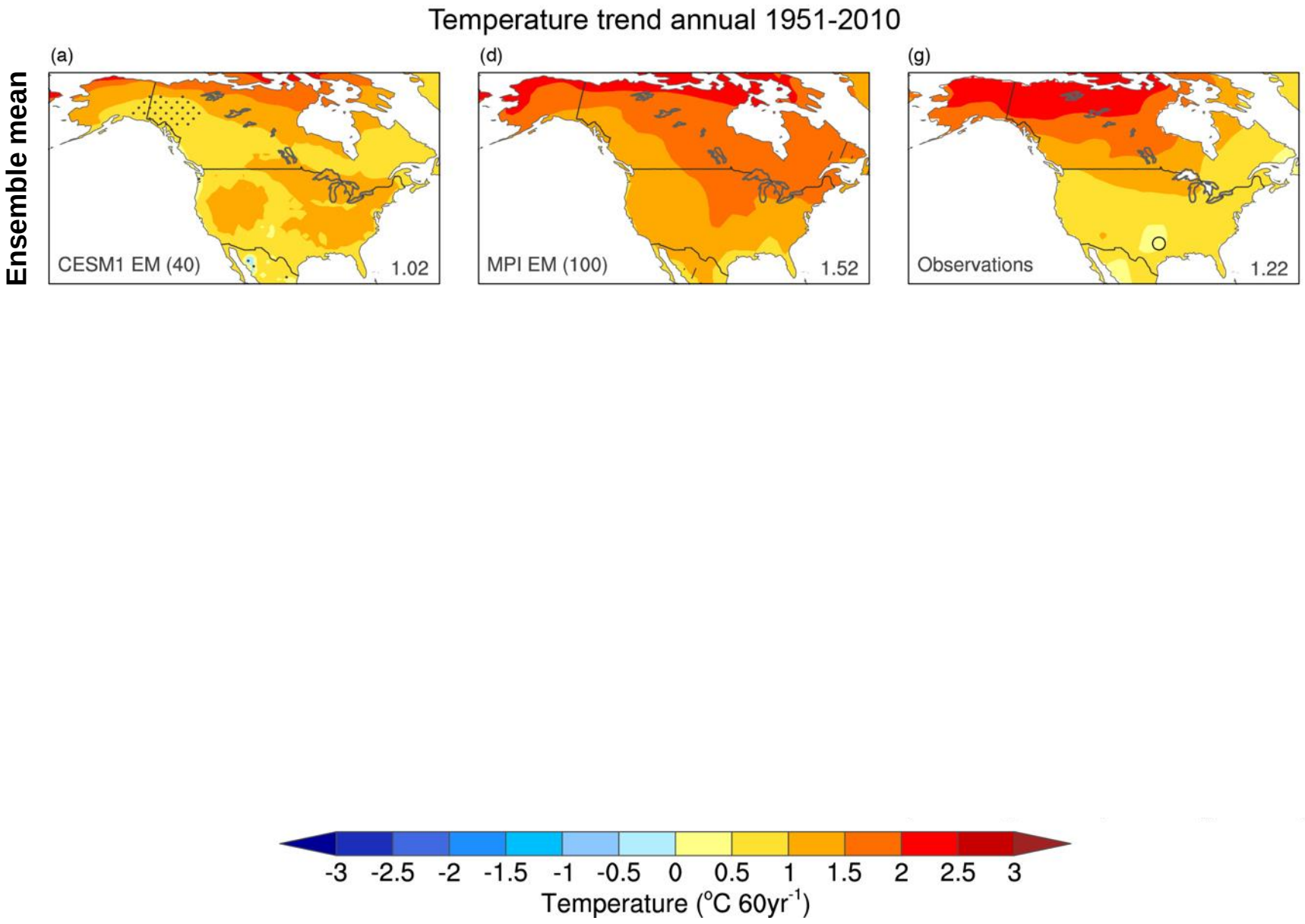
www.cesm.ucar.edu/projects/community-projects/MMLEA/

Application #1: Interpretation of observational record



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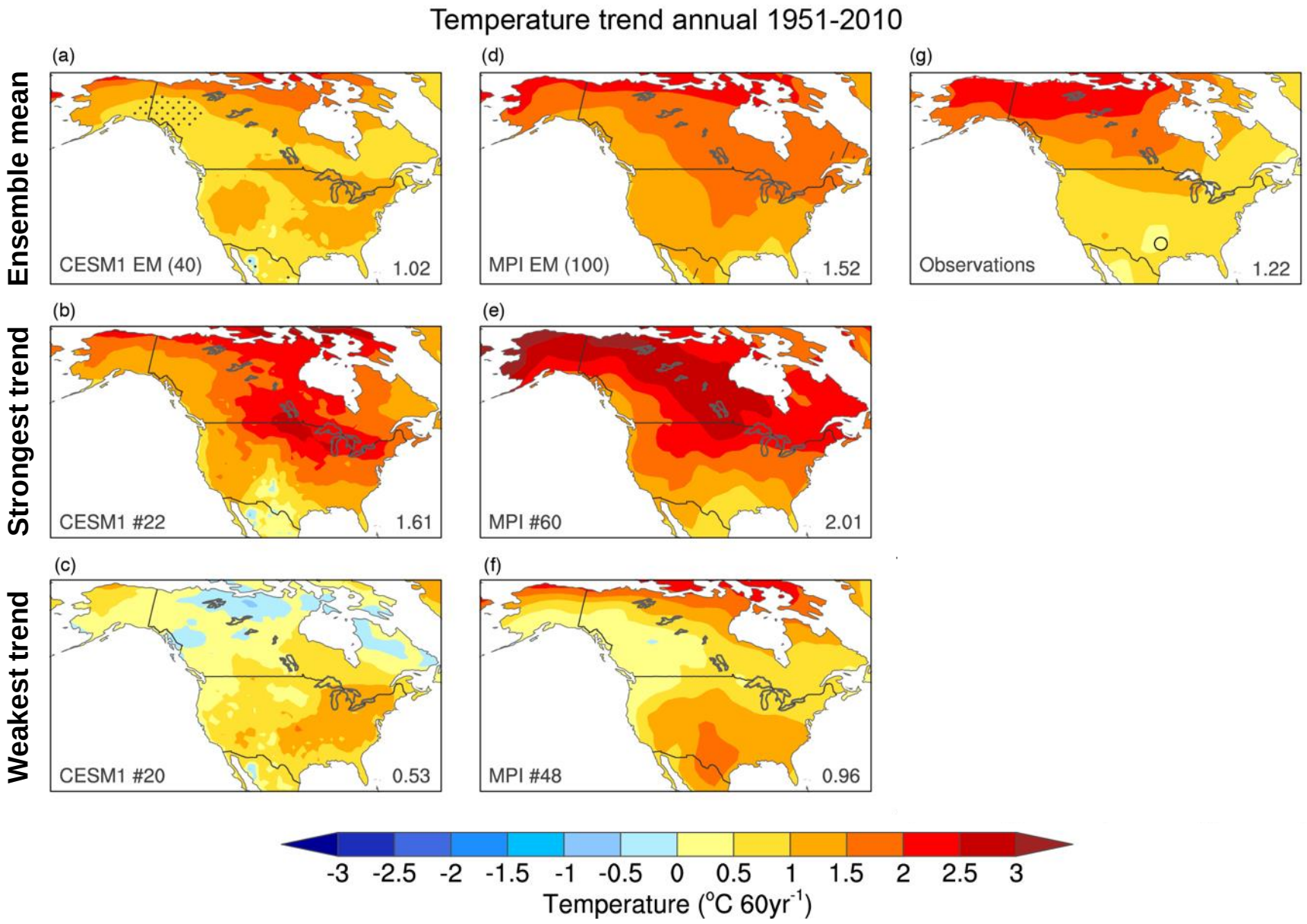

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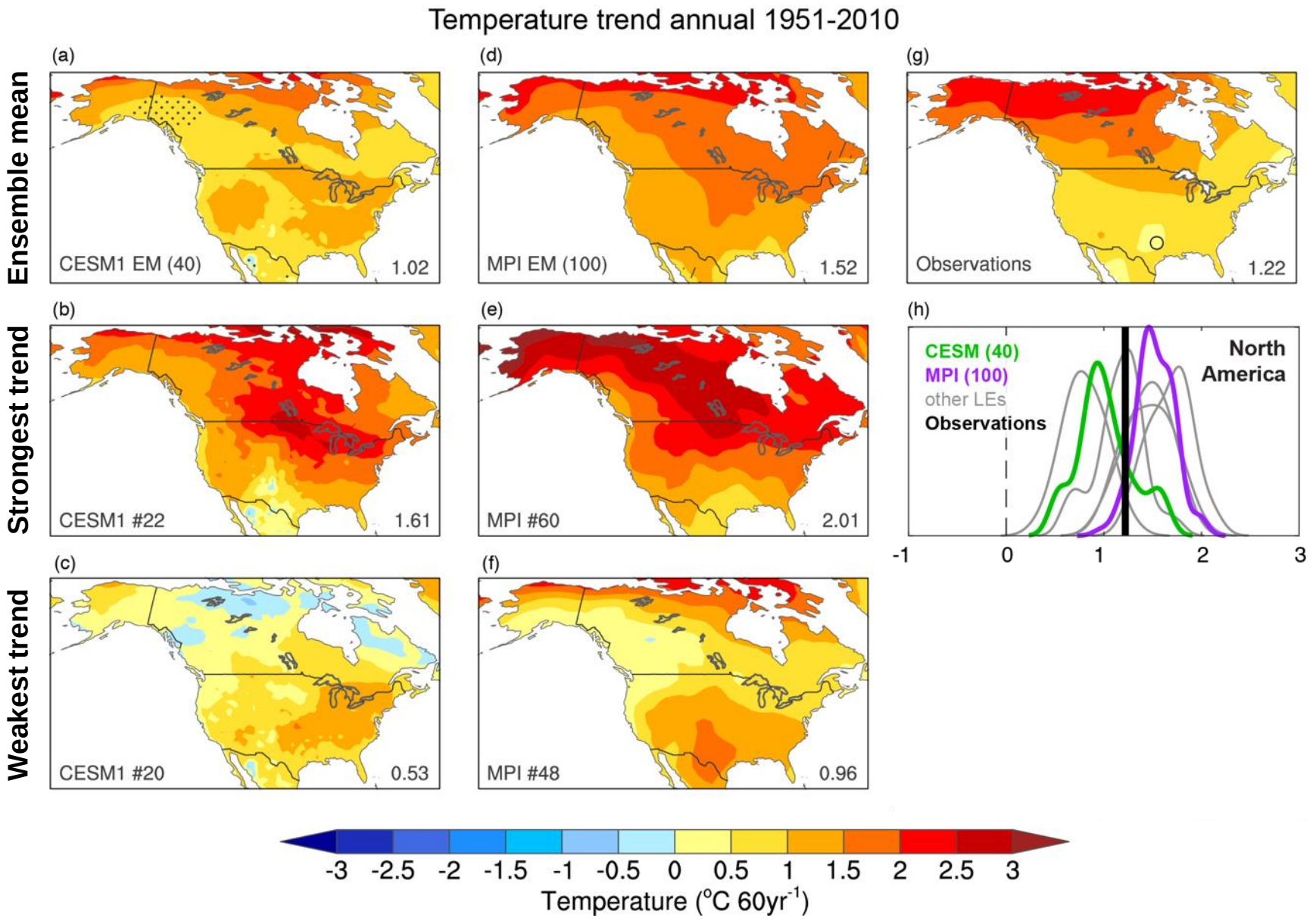

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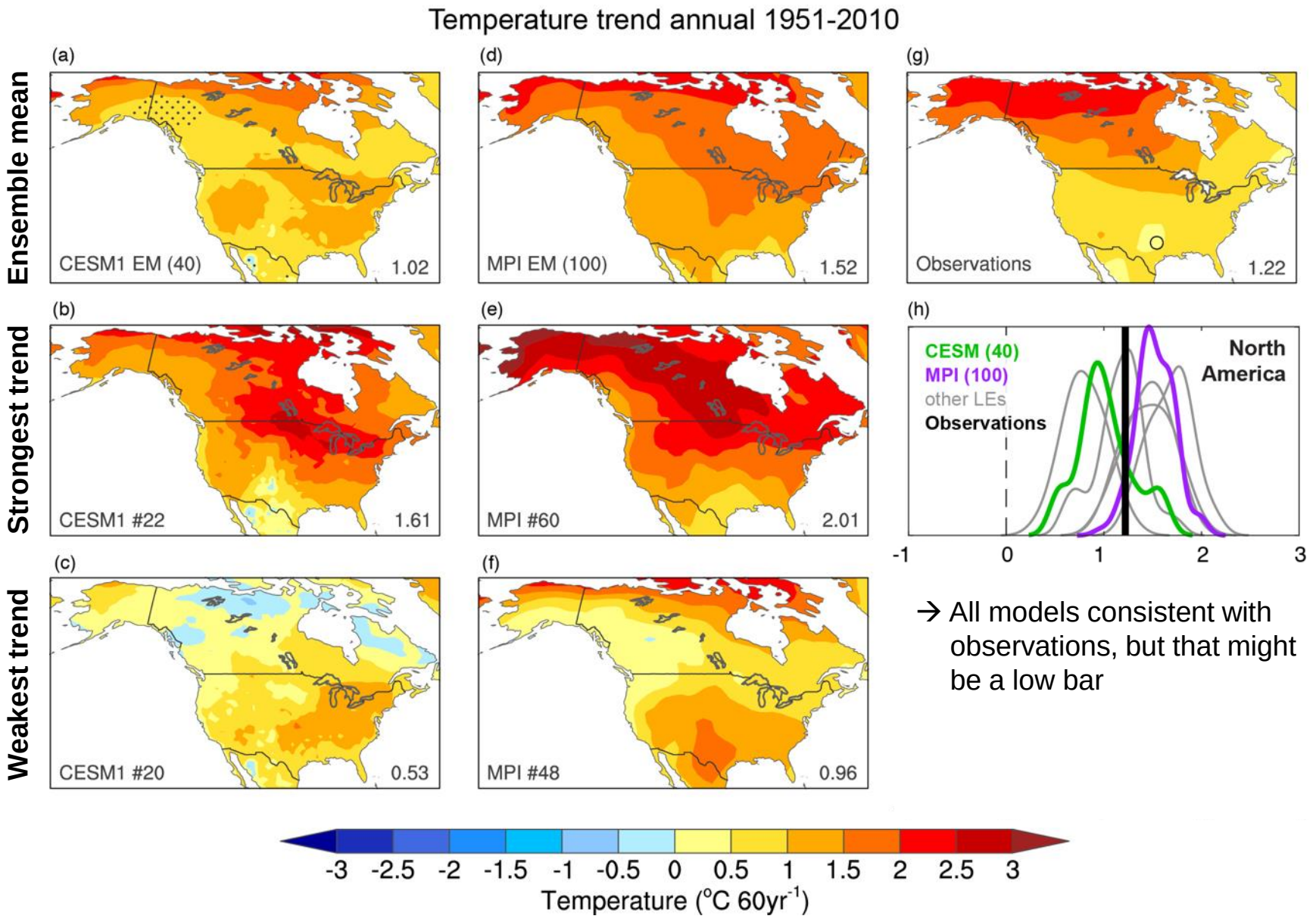
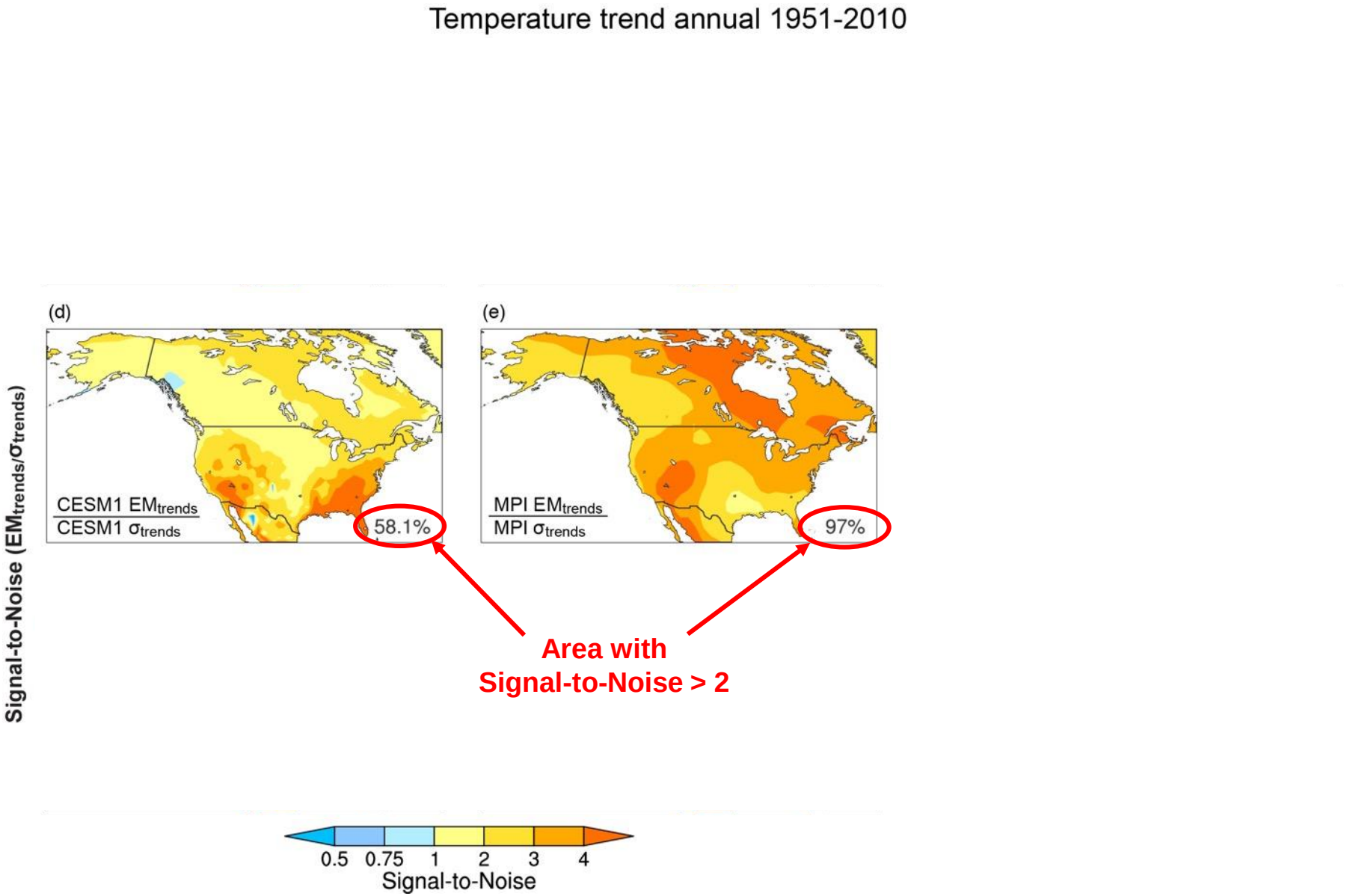


→ All models consistent with observations, but that might be a low bar

Application #2: Evaluation of model variability



Deser at al. (submitted)

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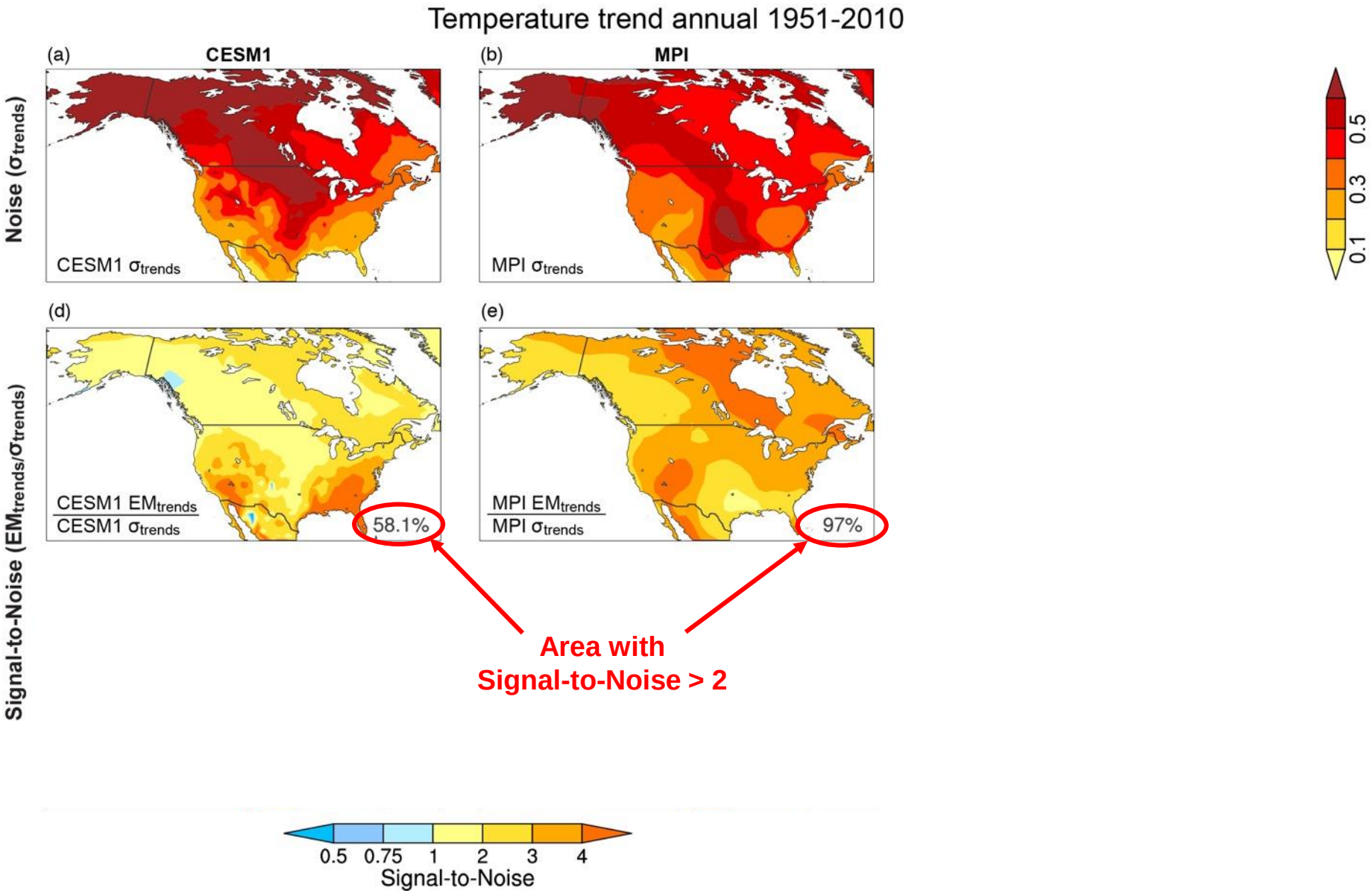

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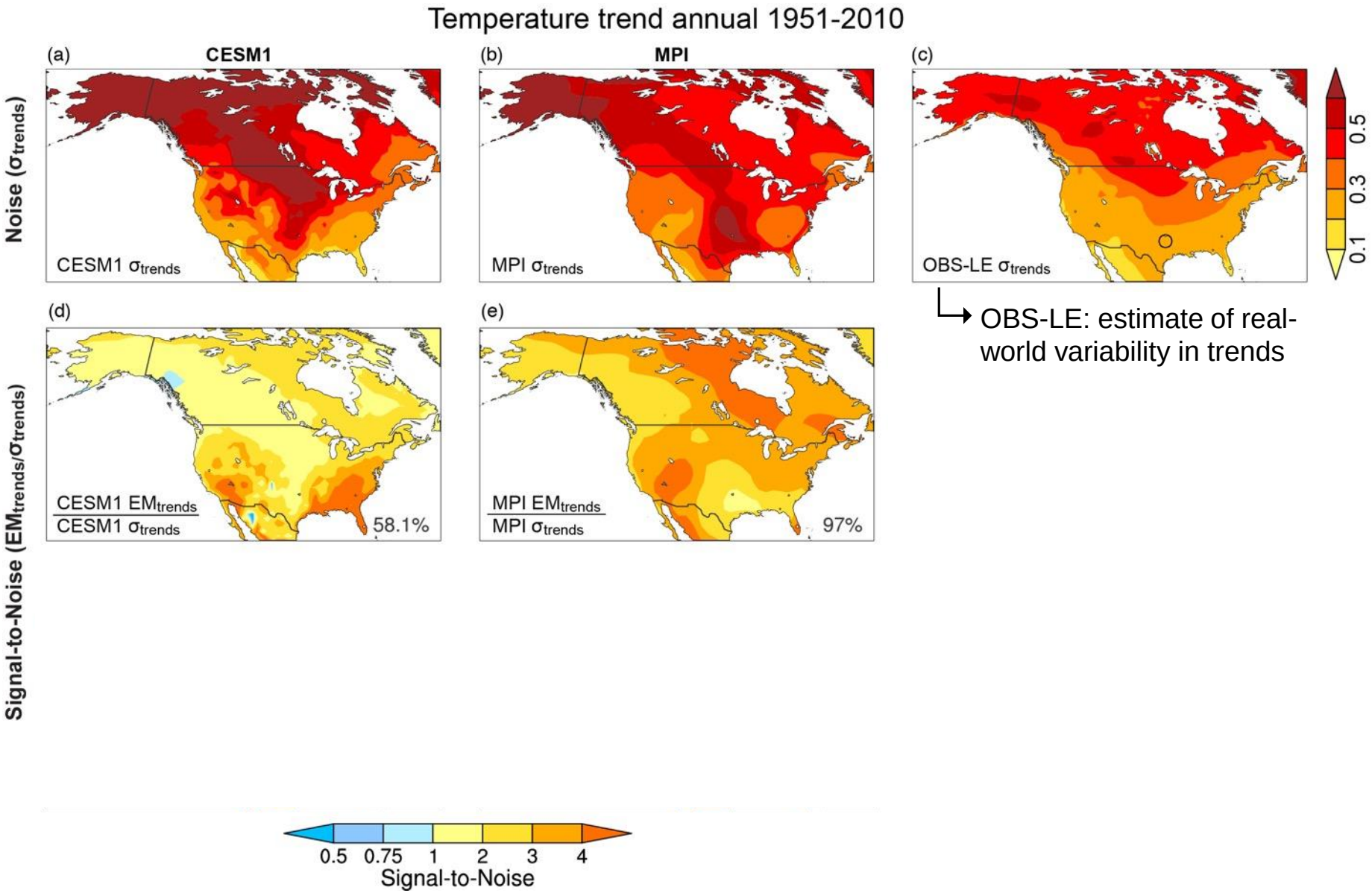
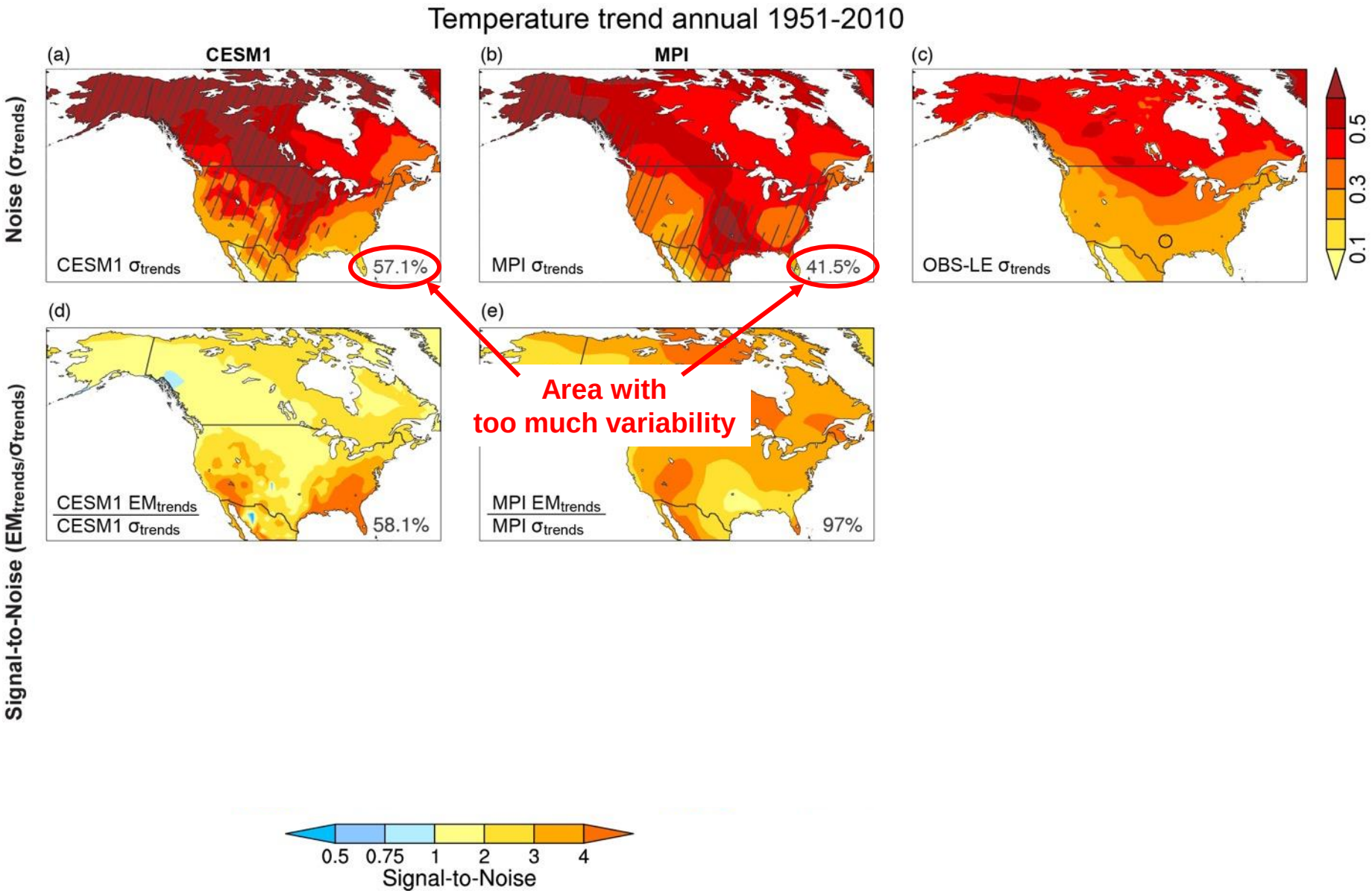


OBS-LE: estimate of real-world variability in trends

Application #2: Evaluation of model variability



Deser at al. (submitted)

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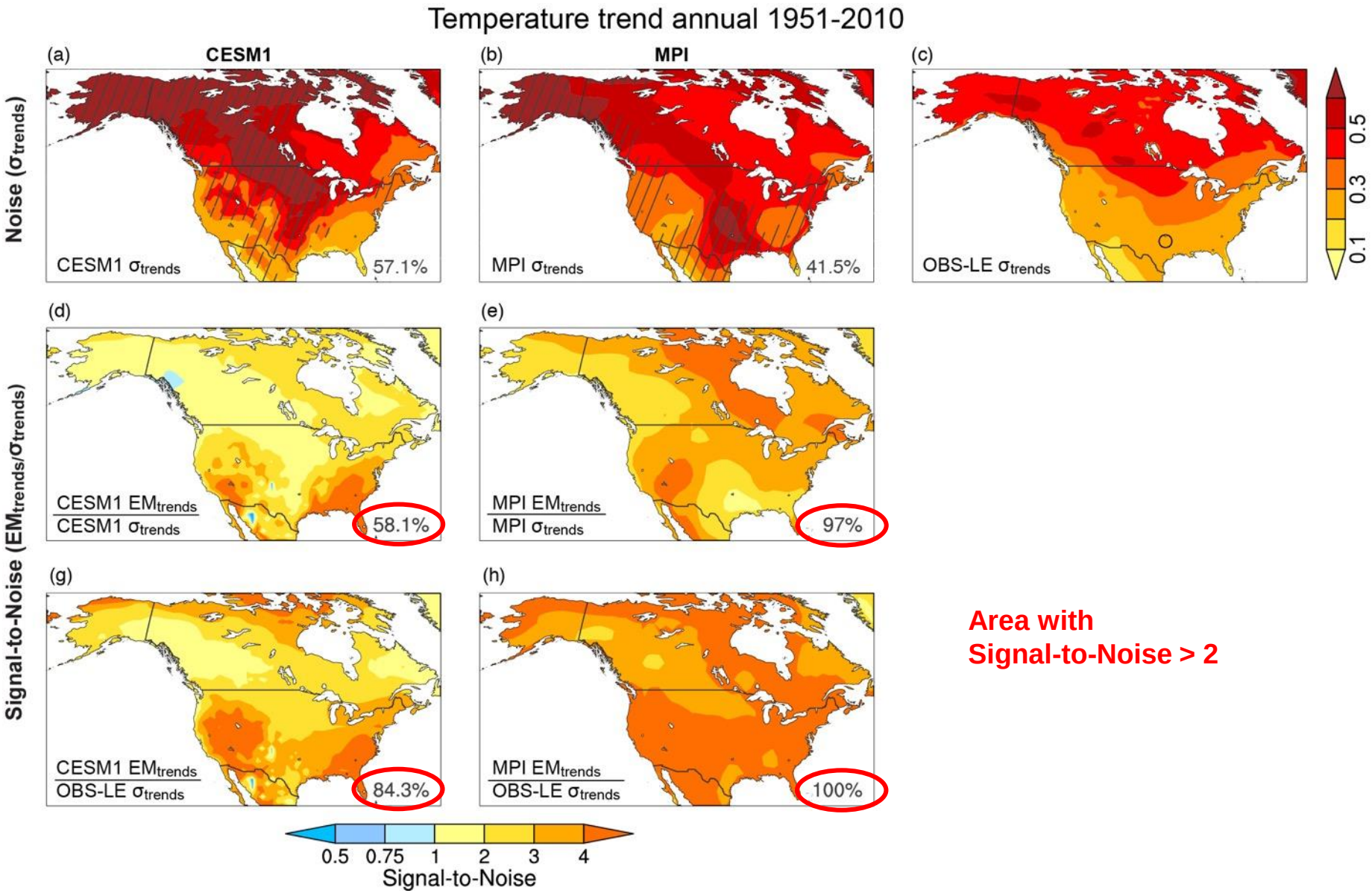
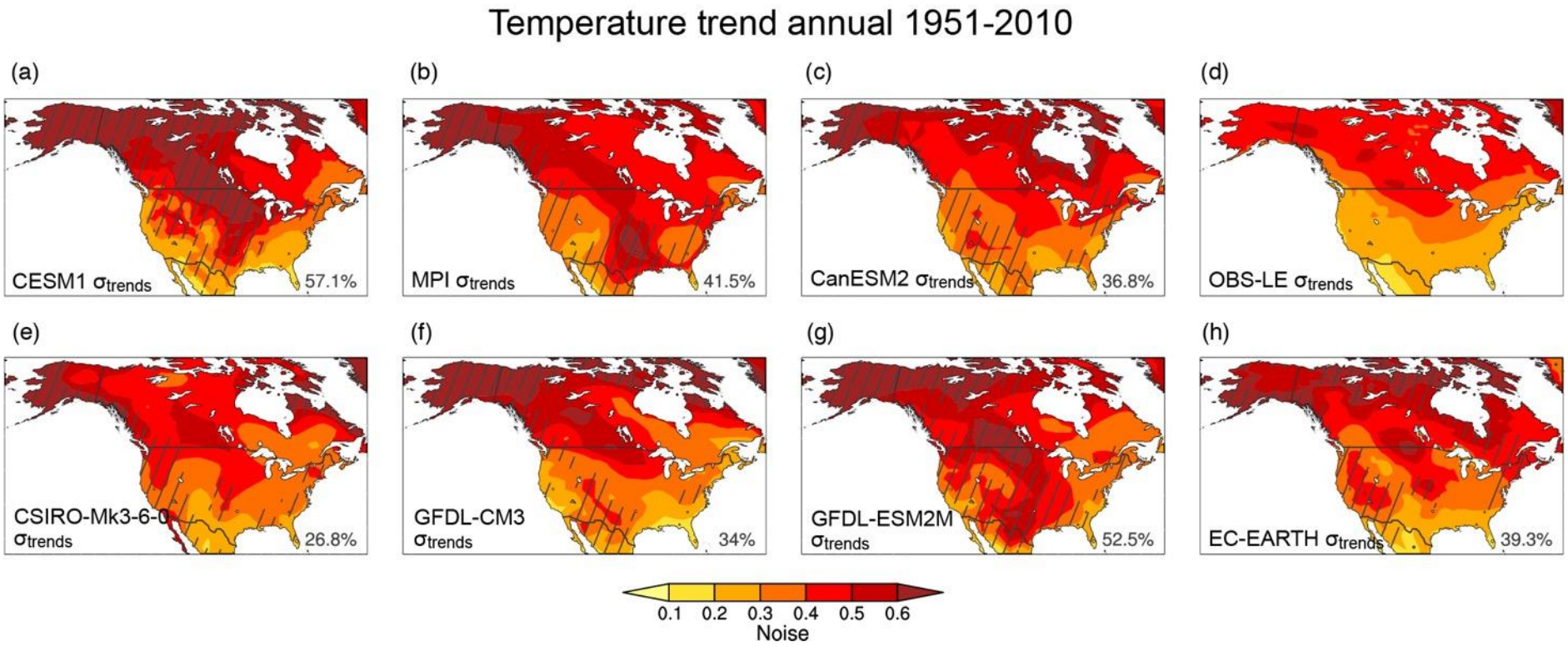
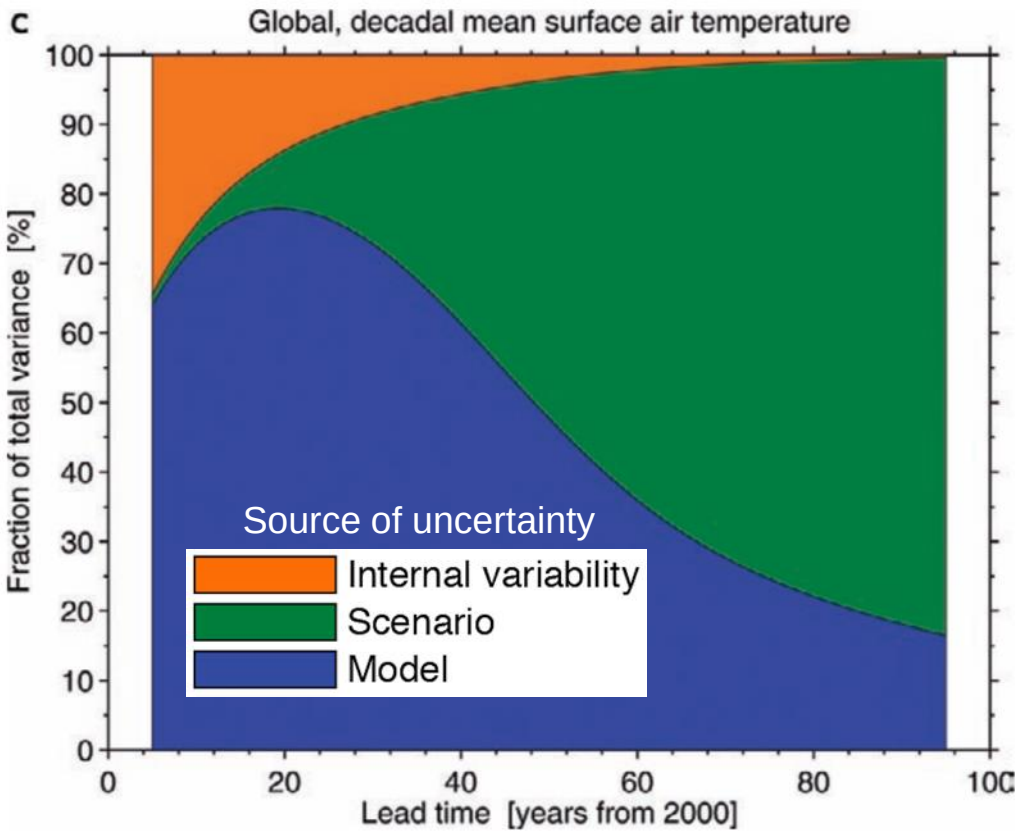


Area with Signal-to-Noise > 2

Application #2: Evaluation of model variability



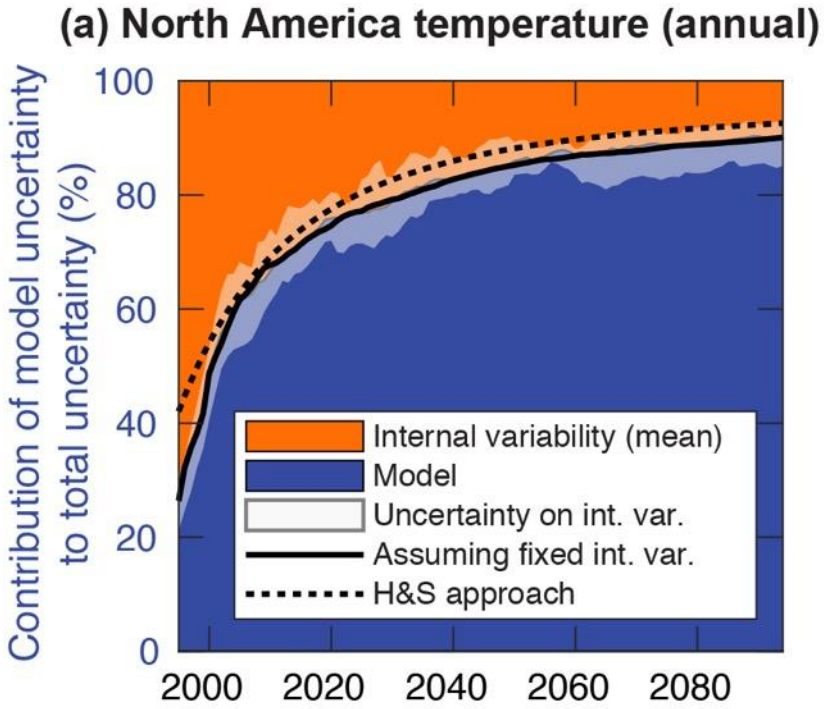
Application #3: Uncertainty partitioning



Didn't have LEs, thus needed to make assumptions about the forced response of each model: 4th order polynomial fit to a single ensemble member

Hawkins and Sutton (2009)

Application #3: Uncertainty partitioning



Repeat H&S09 analysis with 7 LEs

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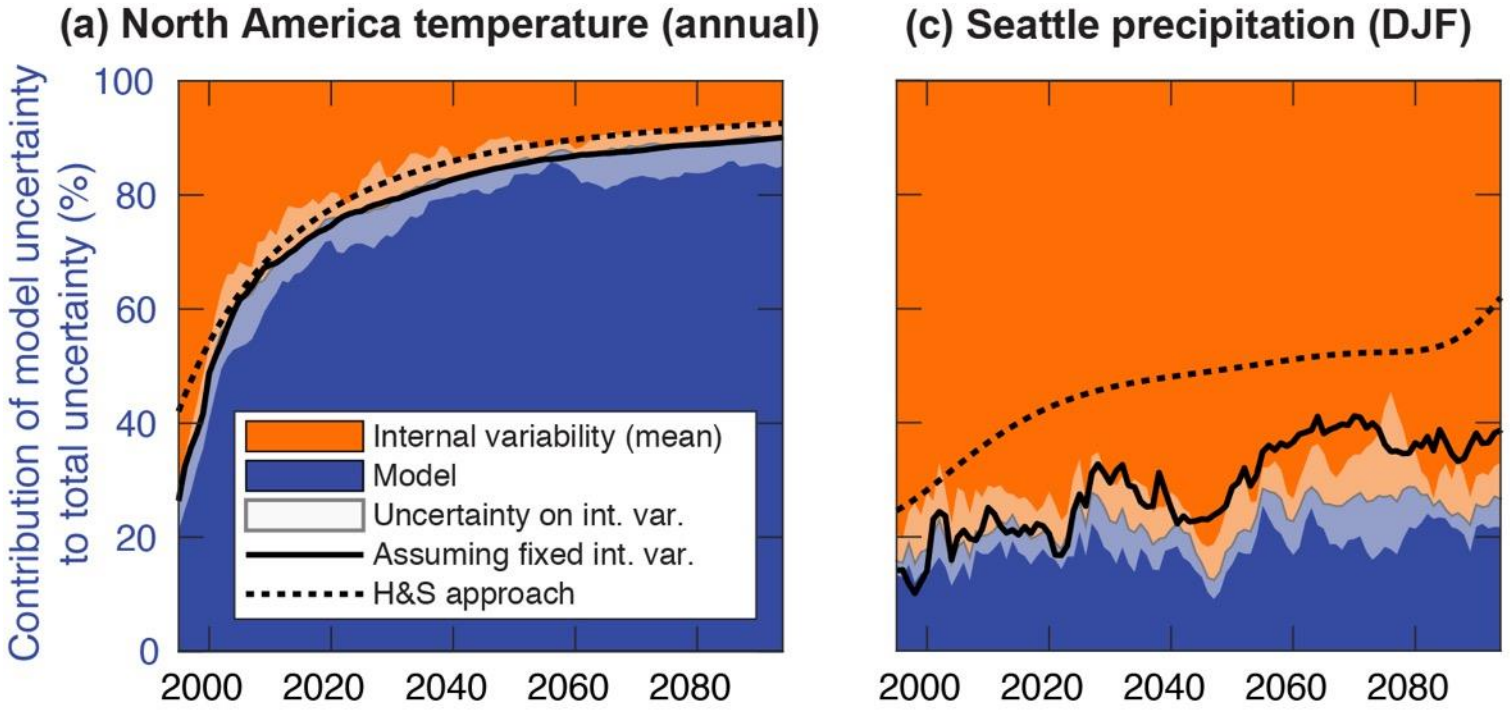

Other applications and documentation of MMLE Archive

Strength in Numbers: The Utility of Large Ensembles with Multiple Earth System Models

US CLIVAR Working Group on Large Ensembles
[C. Deser*, F. Lehner, K.B. Rodgers, T. Ault, T.L. Delworth, P.N. DiNezio, A. Fiore, C. Frankignoul, J. C. Fyfe, D.E. Horton, J.E. Kay, R. Knutti, N.S. Lovenduski, J. Marotzke, K.A. McKinnon, S. Minobe, J. Randerson, J.A. Screen, I.R. Simpson and M. Ting]

Perspective submitted 21 June 2019 to *Nature Climate Change*

Feedback welcome on MMLE Archive
Contributions welcome
Updates and bug fixes planned later this summer