Earth System Prediction using CESM

Stephen Yeager
Climate and Global Dynamics Laboratory, NCAR

August 12, 2022

This material is based upon work supported by the National Center for Atmospheric Research, which is a major facility sponsored by the National Science Foundation under Cooperative Agreement No. 1852977.

Seasonal to Decadal
Earth System Prediction using CESM

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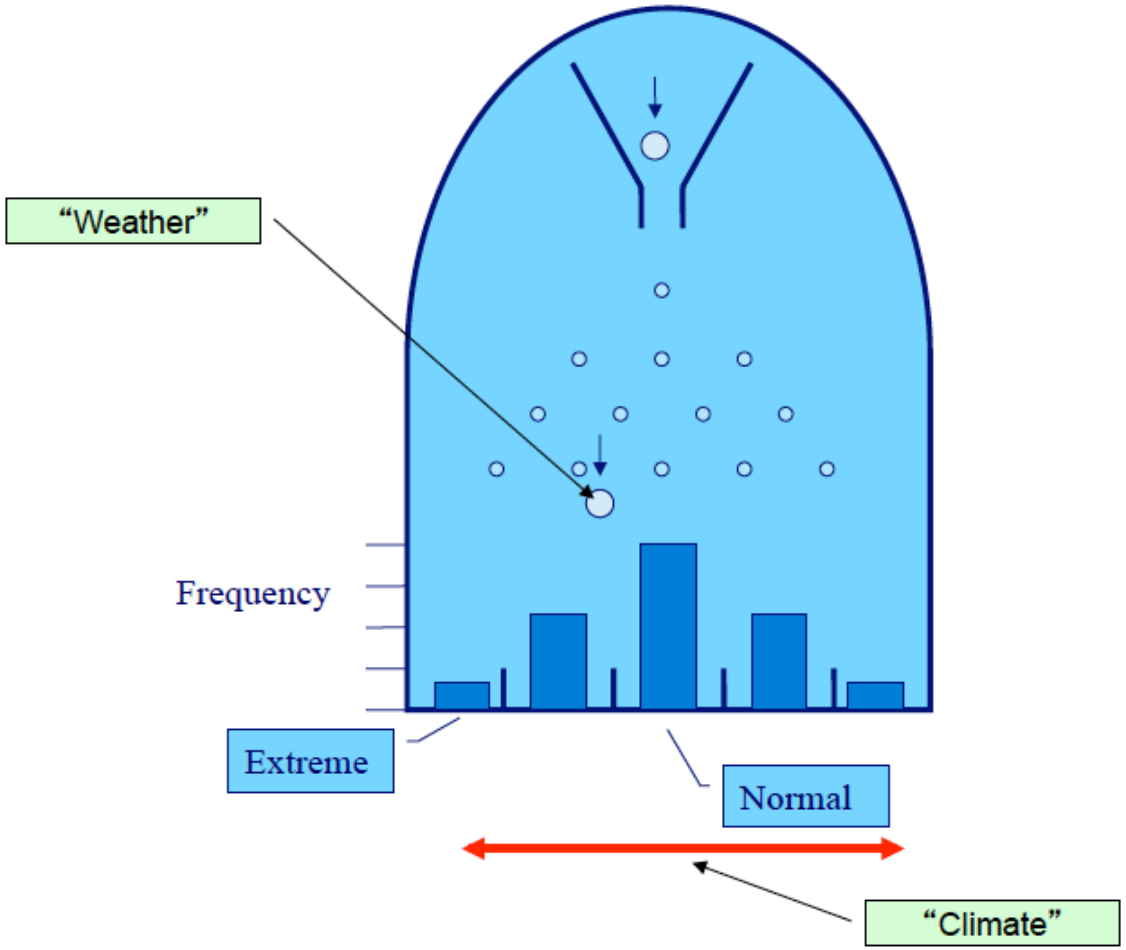
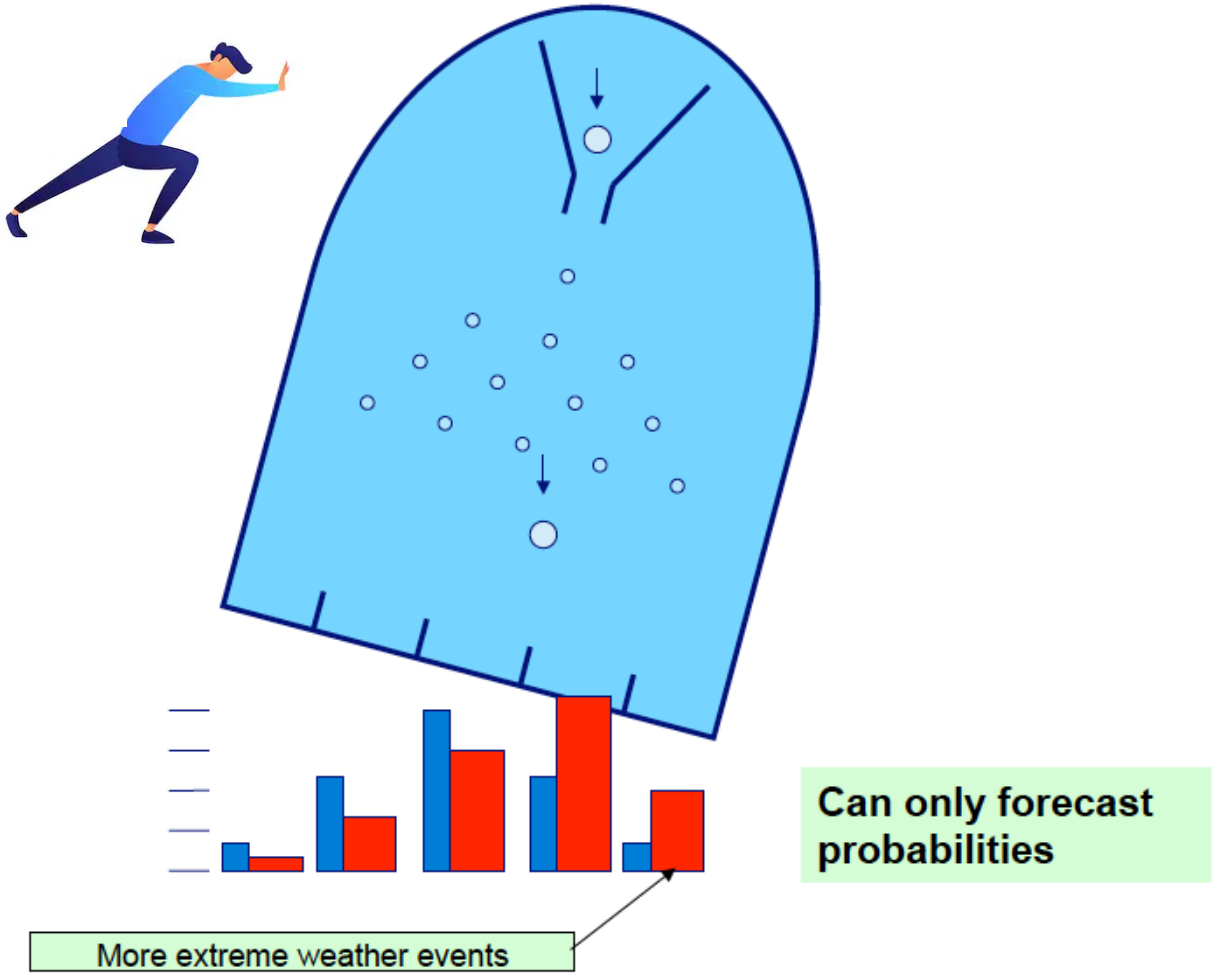
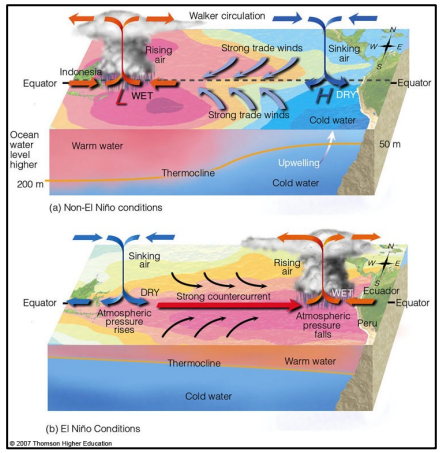
Aim to use CESM for climate prediction, not weather prediction!



Greenhouse
Gas Emissions

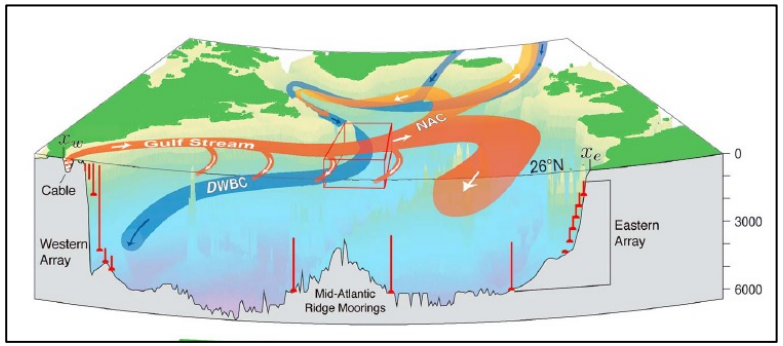


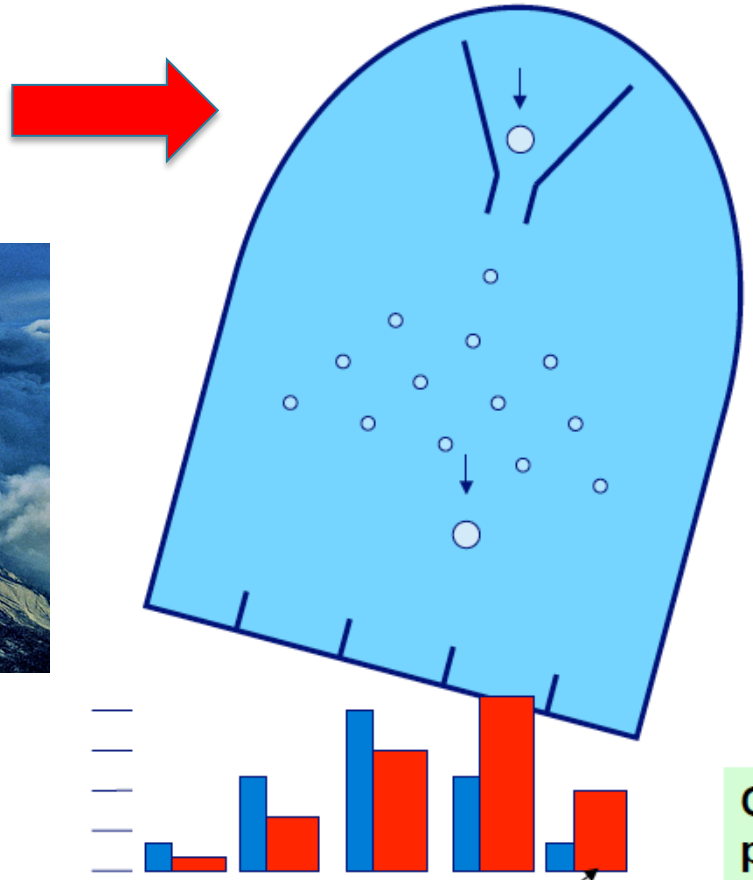
ENSO Cycles



Volcanic Eruptions

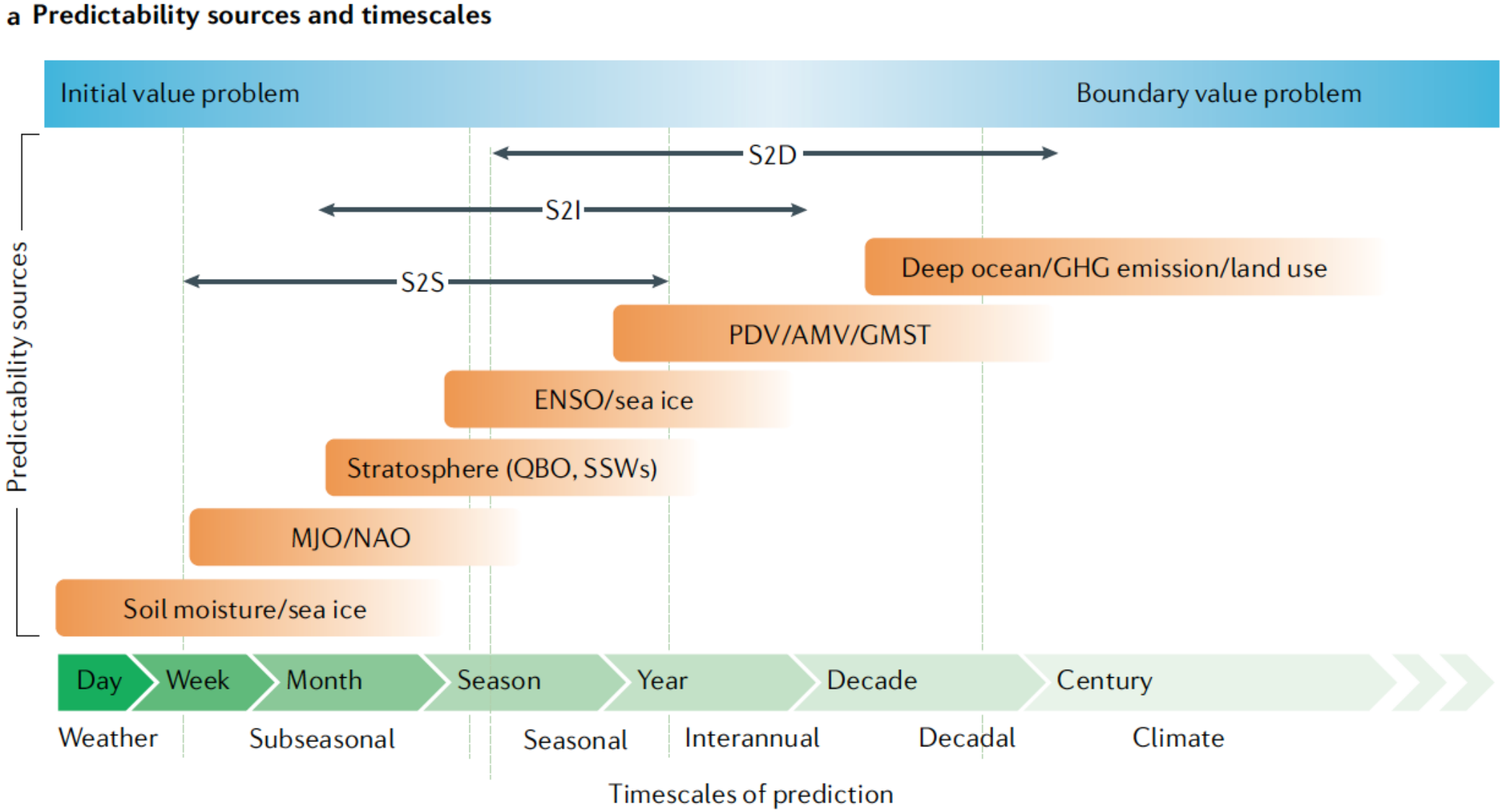
Ocean Heat Transport





More extreme weather events

Can only forecast probabilities



Meehl et al. (2021, *Nature Reviews*, https://doi.org/10.1038/s43017-021-00155- x)

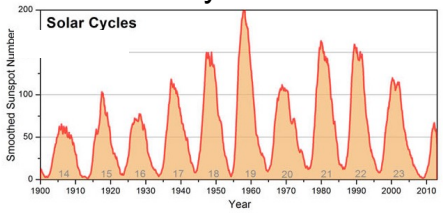
Forced Variability & Change

Greenhouse Gases

Biomass Emissions

Volcanic Eruptions

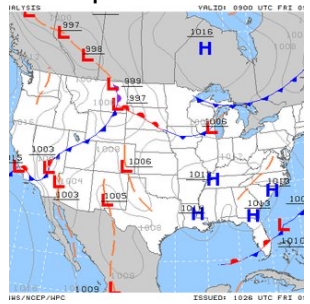
Solar Cycles



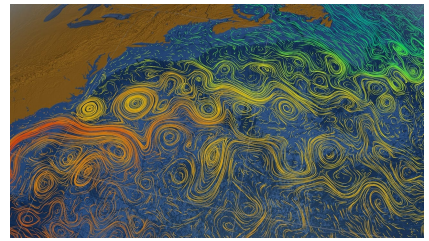
Regional Climate Statistics

Internal Variability

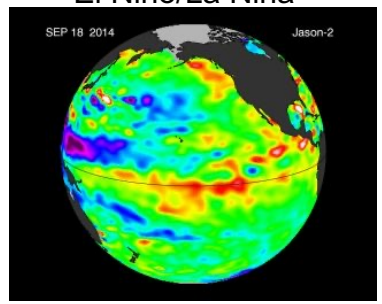
Atmospheric Turbulence



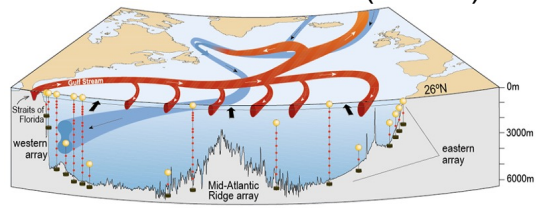
Oceanic Turbulence



El Niño/La Niña



Atlantic Meridional Overturning Circulation (AMOC)



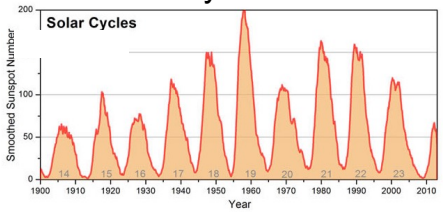
Forced Variability & Change

Greenhouse Gases

Biomass Emissions

Volcanic Eruptions

Solar Cycles



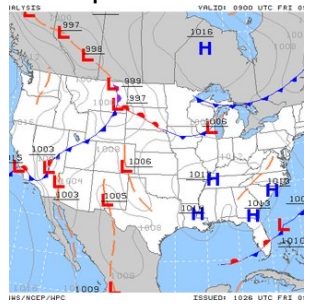
Ensemble mean (signal) = forced variability/change

Regional Climate Statistics

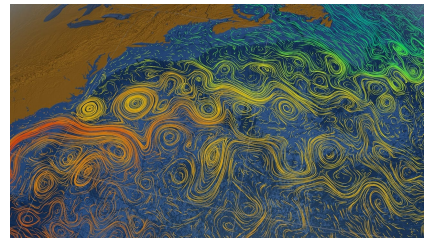
SMILEs (Single Model Initial-condition Large Ensembles)

Internal Variability

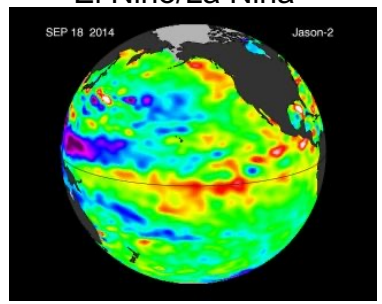
Atmospheric Turbulence



Oceanic Turbulence



El Niño/La Niña



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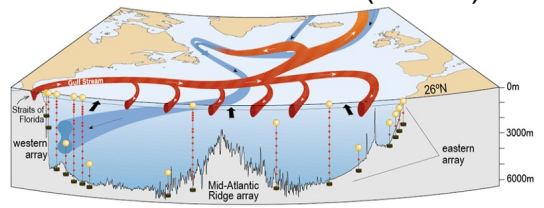


Ensemble spread (noise) = internal variability ("irreducible uncertainty")

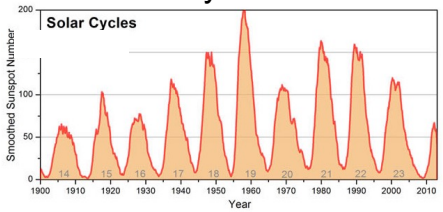
Forced Variability & Change

Greenhouse Gases

Biomass Emissions

Volcanic Eruptions

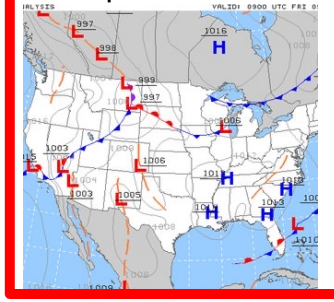
Solar Cycles



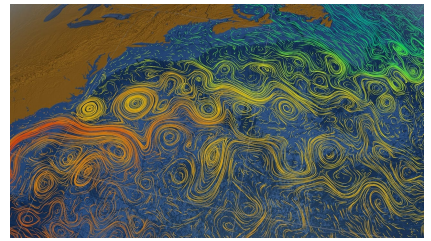
Regional Climate Statistics

Internal Variability

Atmospheric Turbulence



Oceanic Turbulence



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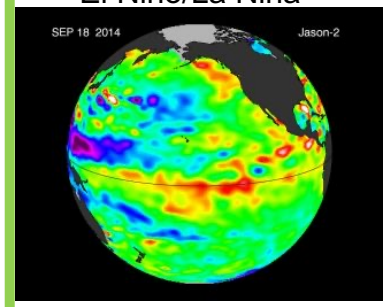
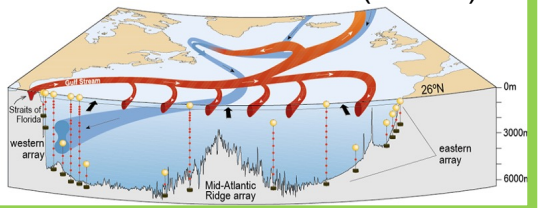


Atlantic Meridional Overturning Circulation (AMOC)

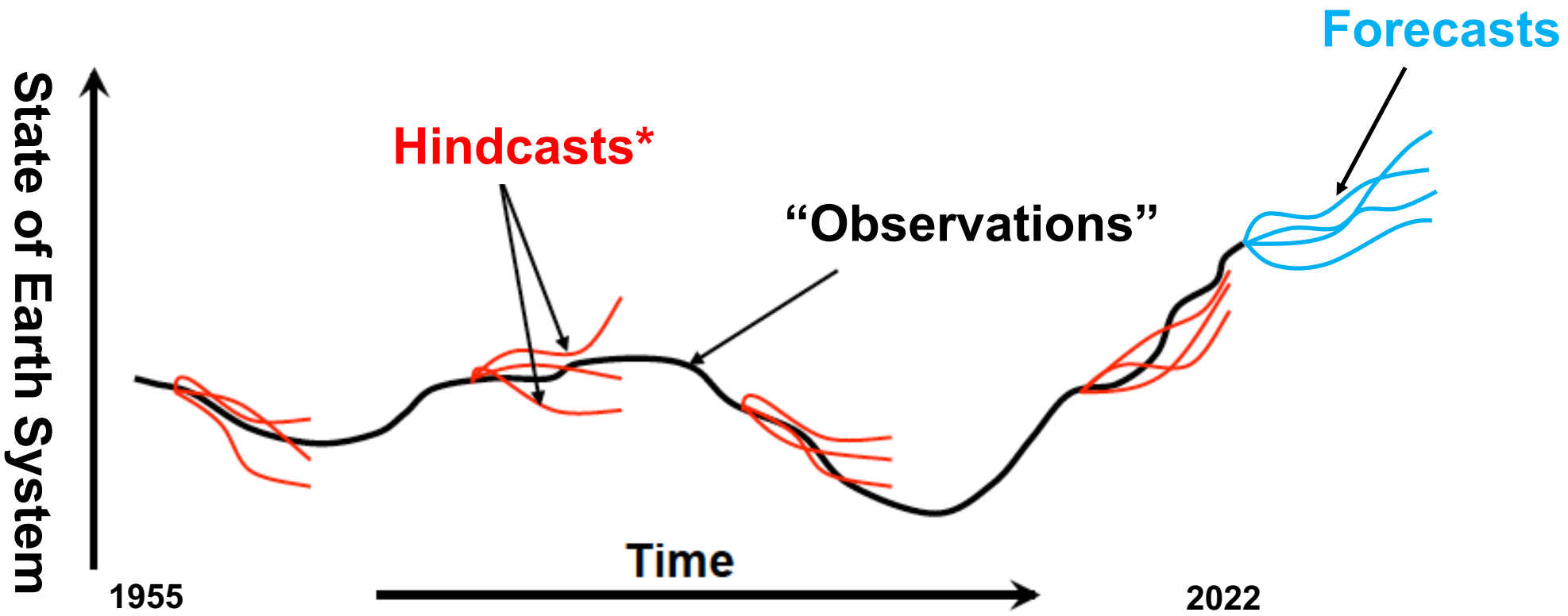


Initialized S2D Prediction Ensembles

Ensemble mean (signal) =
forced variability/change +
predictable internal variability

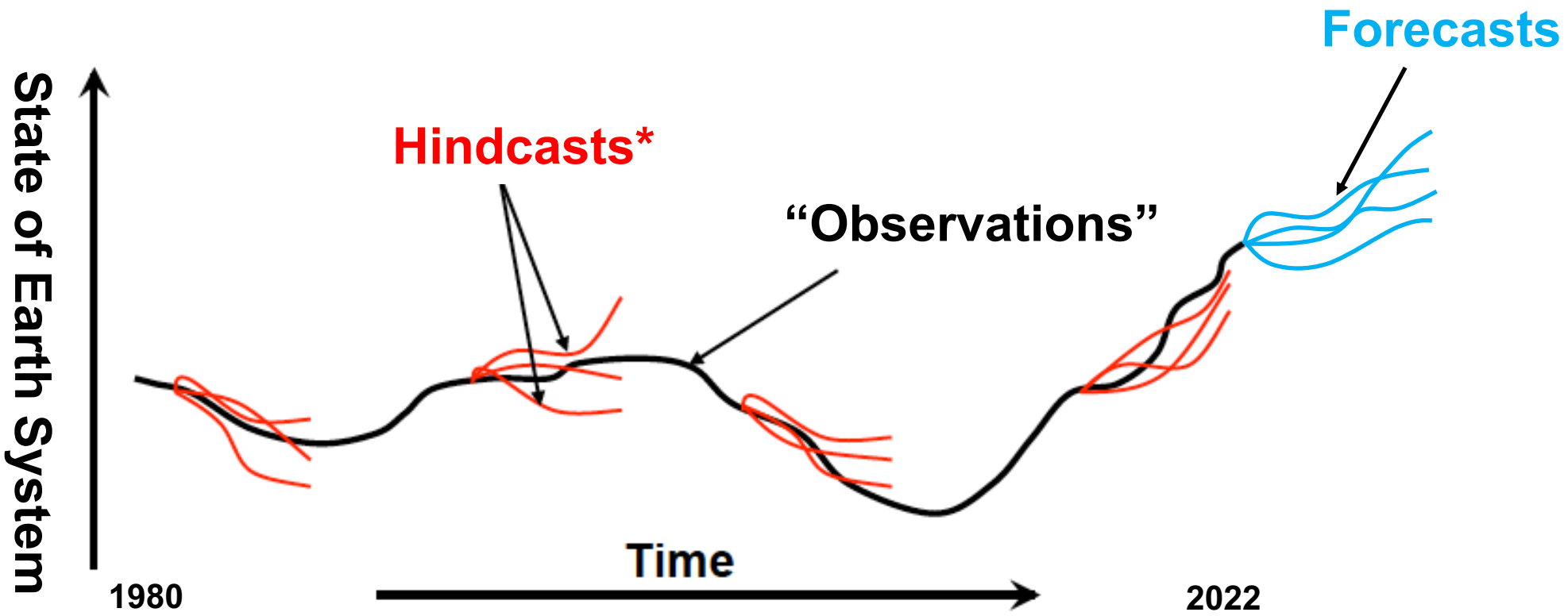
Ensemble spread (noise) =
unpredictable internal variability

Decadal Prediction System Design



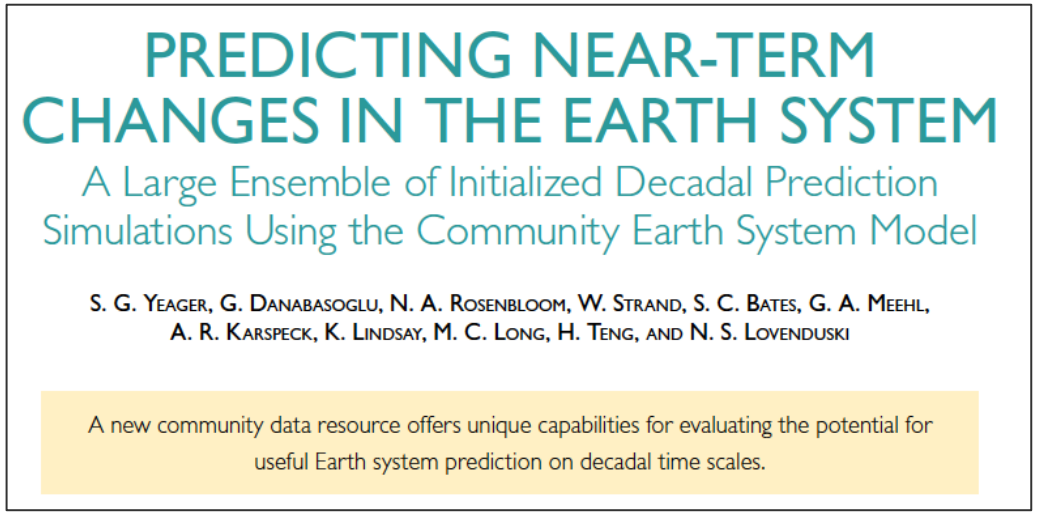
- Ensemble simulations are ~10-years long & initialized every year
- Aim to verify hindcasts against observed **annual or multiyear-average** climate statistics

Seasonal Prediction System Design



- Ensemble simulations are ~12-months long & initialized every month
- Aim to verify hindcasts against observed **monthly or seasonal-average** climate statistics

The CESM Decadal Prediction Large Ensemble (CESM-DPLE)


PREDICTING NEAR-TERM CHANGES IN THE EARTH SYSTEM

A Large Ensemble of Initialized Decadal Prediction Simulations Using the Community Earth System Model

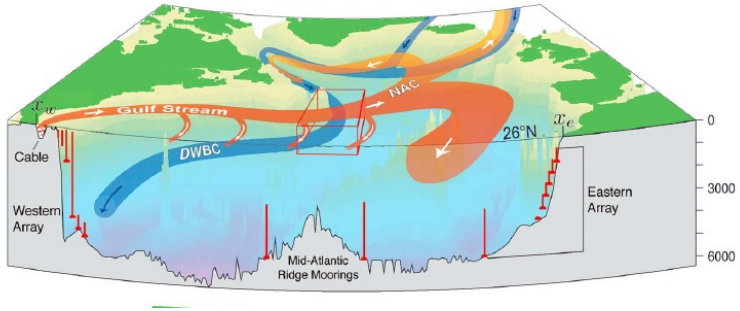
S. G. Yeager, G. Danabasoglu, N. A. Rosenbloom, W. Strand, S. C. Bates, G. A. Meehl, A. R. Karspeck, K. Lindsay, M. C. Long, H. Teng, and N. S. Lovenduski

A new community data resource offers unique capabilities for evaluating the potential for useful Earth system prediction on decadal time scales.

BAMS, 2018, doi:10.1175/BAMS-D-17-0098.1

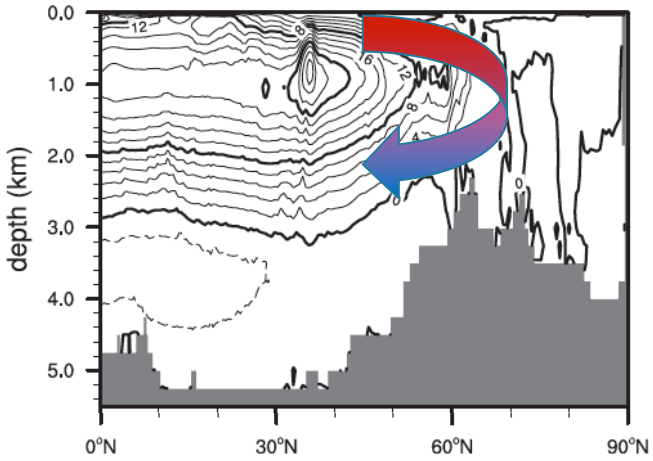
- ~26,000 sim-year experiment using CESM1
- Includes ocean biogeochemical fields
- http://www.cesm.ucar.edu/projects/community-projects/DPLE/

DP systems leverage predictability coming from slow ocean adjustments

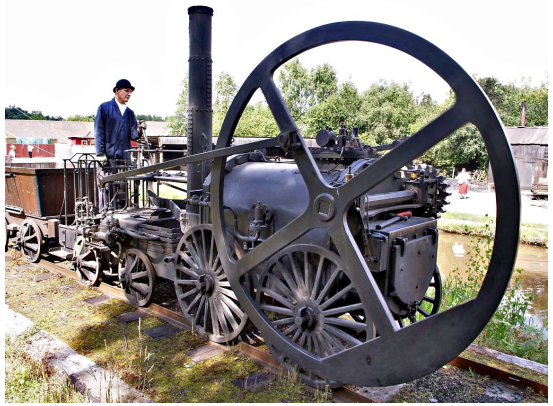


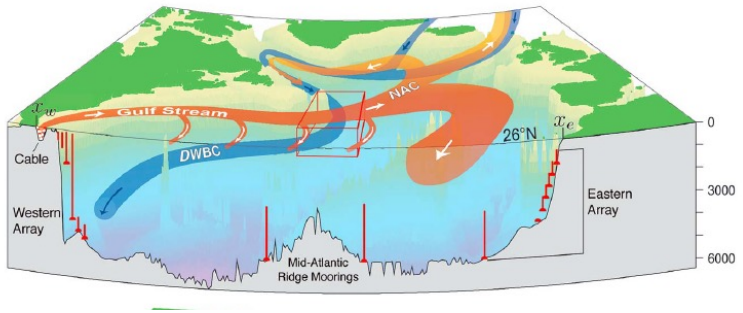
Side view

"AMOC" or "overturning circulation"



AMOC gets strong/weak on decadal timescales





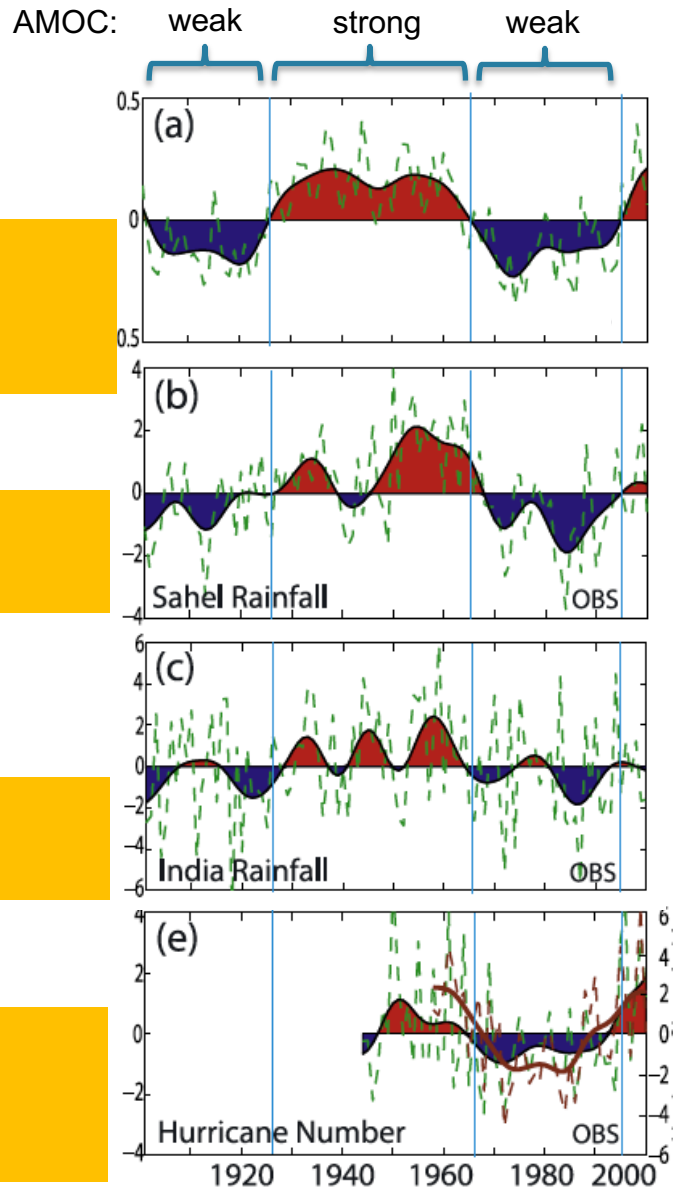
Changes in the strength of the Atlantic Ocean circulation

North Atlantic Ocean temperatures

Rainfall in Africa

Rainfall in India

Atlantic Hurricane Activity

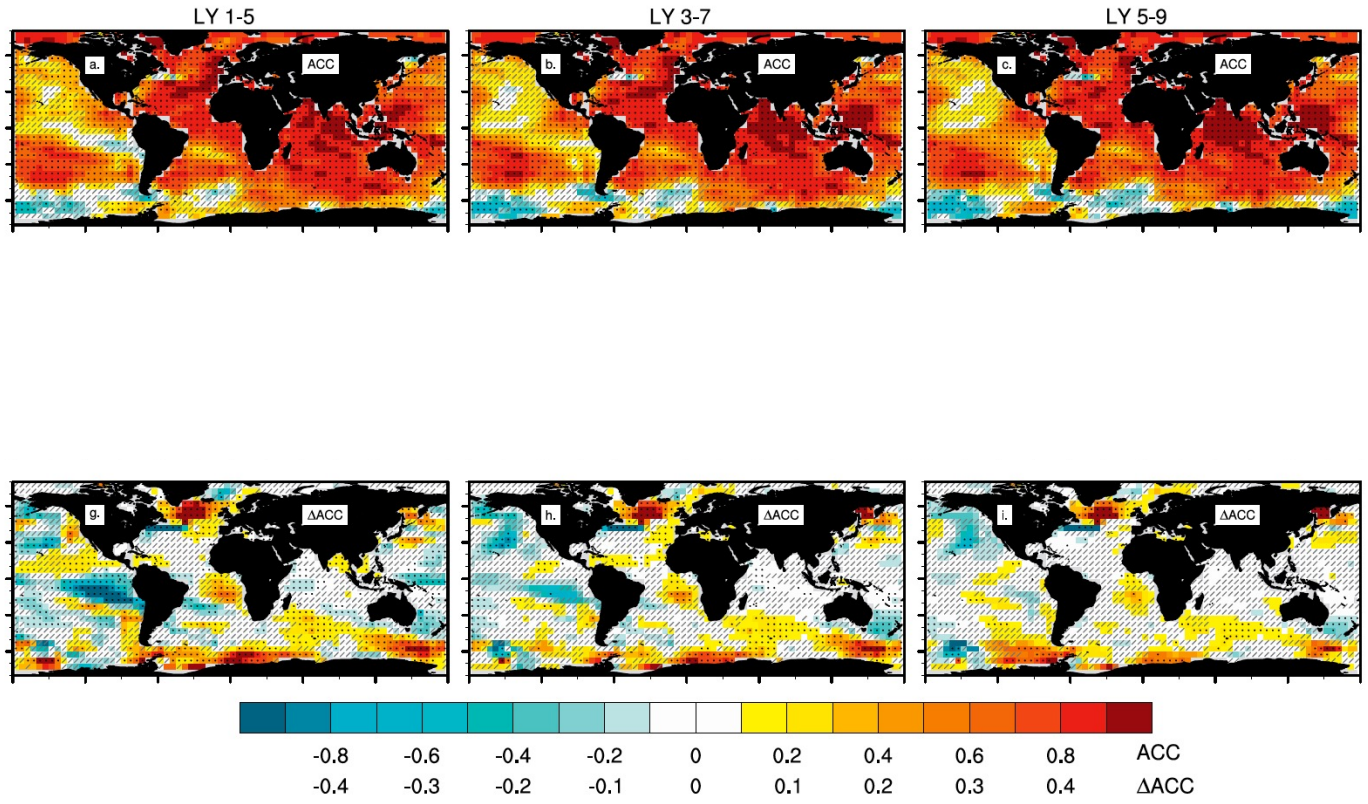


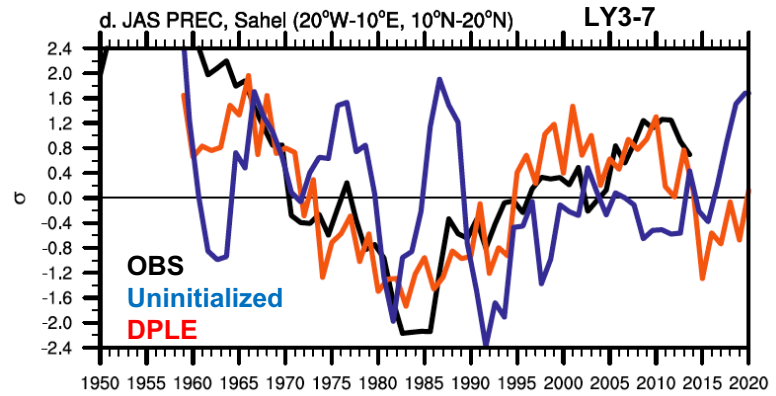
Plots from Zhang & Delworth (*GRL* 2006, doi:10.1029/2006GL026267)

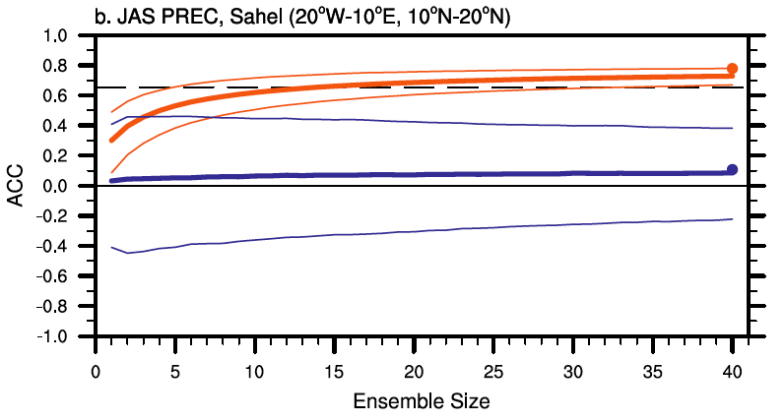
CESM-DPLE Skill for Sea Surface Temperature & Precipitation

SST skill

Improvement over uninitialized







- High, long-lasting skill in N. Atlantic attributable to ocean (AMOC) initialization
- Noteworthy skill at predicting regional climate variations over land (e.g., African Sahel)
- 40-member ensemble helps to maximize skill

Yeager et al. (2018, BAMS)

The CESM2 Seasonal-to-Multiyear Large Ensemble (SMYLE)

The Seasonal-to-Multiyear Large Ensemble (SMYLE) Prediction System using the Community Earth System Model Version 2

Stephen Gerald Yeager[1], Nan Rosenbloom[1], Anne A. Glanville[1], Xian Wu[1], Isla Simpson[1], Hui Li[1], Maria J. Molina[1], Kristen Krumhardt[1], Samuel Mogen[2], Keith Lindsay[1], Danica Lombardozzi[1], Will Wieder[1], Who Myung Kim[1], Jadwiga H. Richter[1], Matthew Long[1], Gokhan Danabasoglu[1], David Bailey[1], Marika Holland[1], Nicole Lovenduski[2], and Warren G. Strand[1]

[1]National Center for Atmospheric Research, Boulder, Colorado, USA

[2]Department of Atmospheric and Oceanic Sciences, University of Colorado, Boulder, Colorado, USA

GMD, 2022, doi: 10.5194/gmd-2022-60

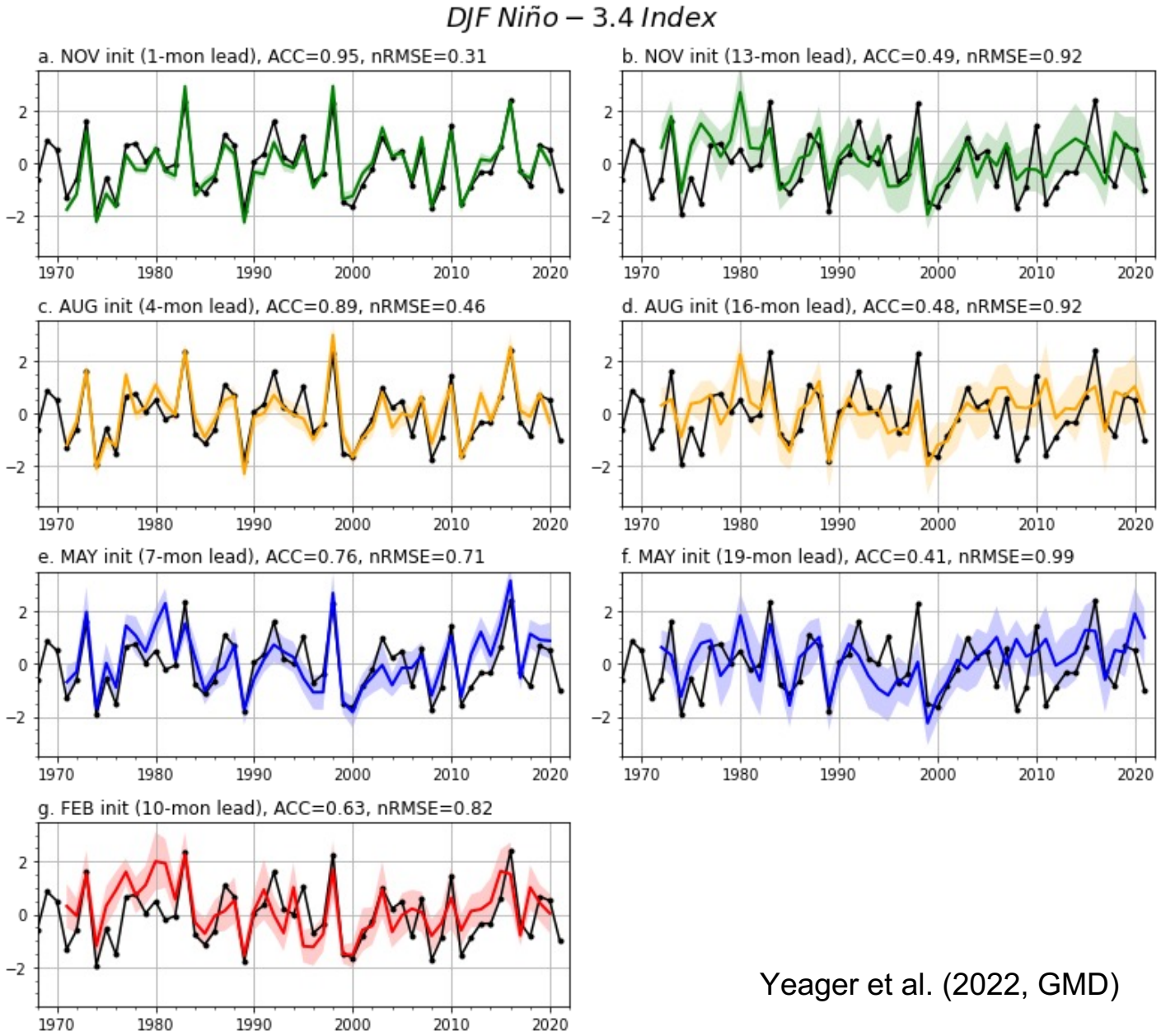
- ~8,000 sim-year experiment using CESM2
- Includes ocean biogeochemical fields
- https://www.cesm.ucar.edu/working-groups/earth-system-prediction/simulations/smyle/

The CESM2 Seasonal-to-Multiyear Large Ensemble (SMYLE)

- 4x/year initialization (1st of Feb, May, Aug, Nov)
- 20-member ensembles
- 24-month simulations

- Good ENSO prediction skill (comparable to operational seasonal forecasting centers)

- **Powerful tool for exploring ENSO-related predictability mechanisms**



Yeager et al. (2022, GMD)

Interested?

- **Get involved in the CESM Earth System Prediction Working Group (ESPWG)!**

  website: https://www.cesm.ucar.edu/working_groups/earth-system-prediction/

  mailing list: http://mailman.cgd.ucar.edu/mailman/listinfo/cesm-espwg

  co-chairs: Steve Yeager (yeager@ucar.edu), Yaga Richter (jrichter@ucar.edu), Kathy Pegion (kpegion@gmu.edu)