Decadal Earth System Prediction using CESM

Stephen Yeager
Climate and Global Dynamics Laboratory, NCAR

NCAR

July 14, 2021

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.

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Alper Altuntas, Jeff Anderson, Susan Bates, Judith Berner, Patrick Callaghan, Julie Caron, Fred Castruccio, Nancy Collins, Gokhan Danabasoglu, Clara Deser, Alice DuVivier, Tim Hoar, Aixue Hu, Alicia Karspeck, Who Kim, Kristen Krumhardt, Jean-François Lamarque, Flavio Lehner, Keith Lindsay, Matt Long, Brian Madeiros, Elizabeth Maroon, Jerry Meehl, Jerry Olson, Kevin Raeder, Yaga Richter, Nan Rosenbloom, Isla Simpson, Gary Strand, Haiyan Teng, Joe Tribbia, …

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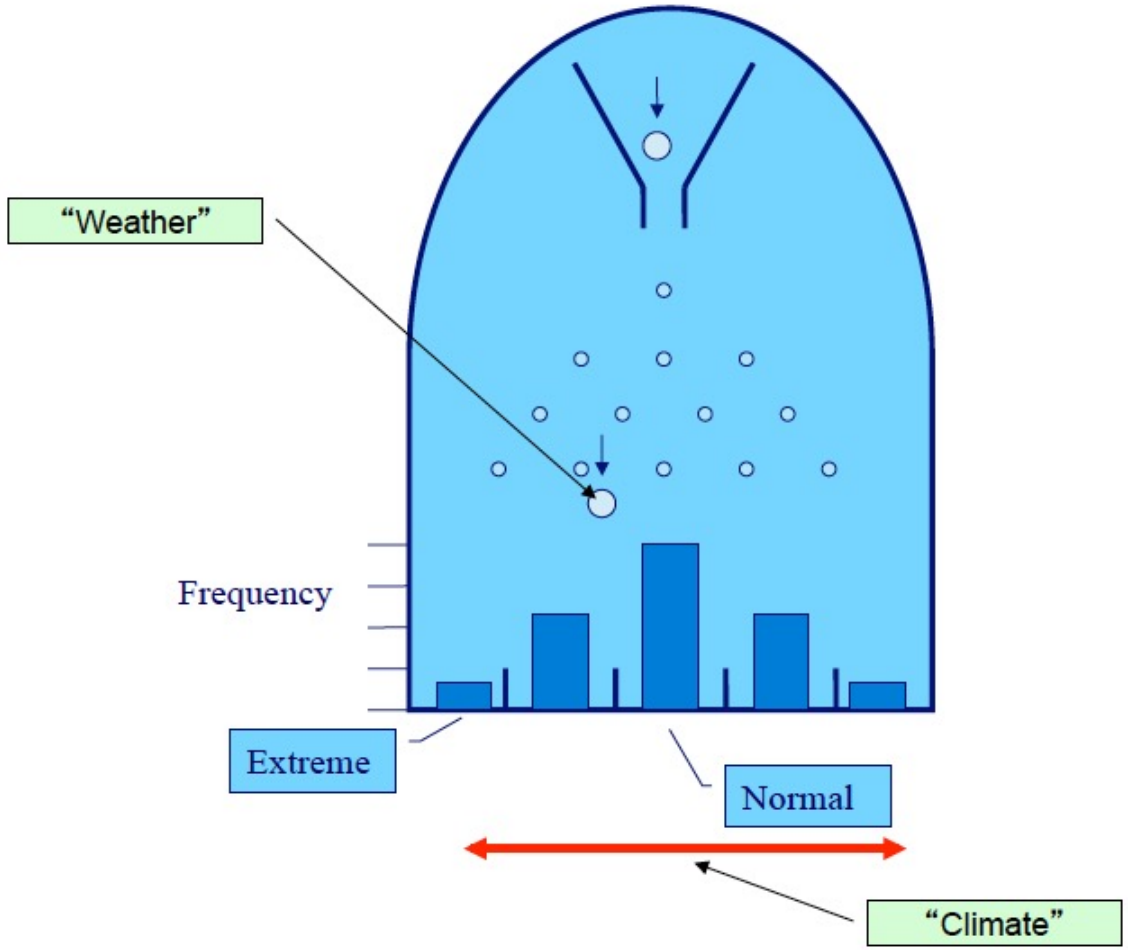
If we can't predict weather beyond ~2 weeks, how can we say anything about what will happen in the next few years to decades?

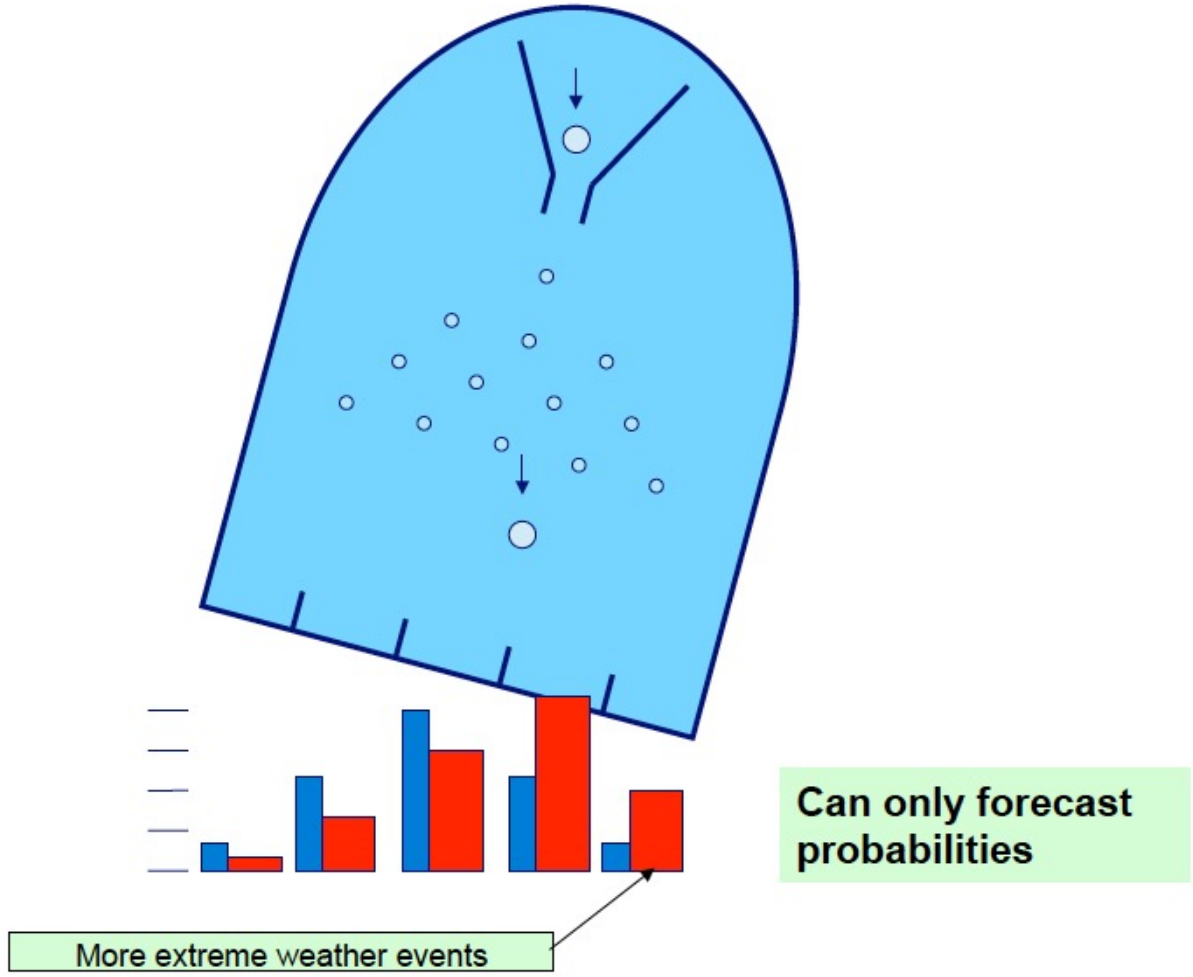
Answer: We aim for decadal climate prediction, not decadal weather prediction!

"Climate" means:
"the statistics of weather"



Answer: We aim for decadal climate prediction, not decadal weather prediction!

Changes in regional climate around the world can happen for a variety of reasons…



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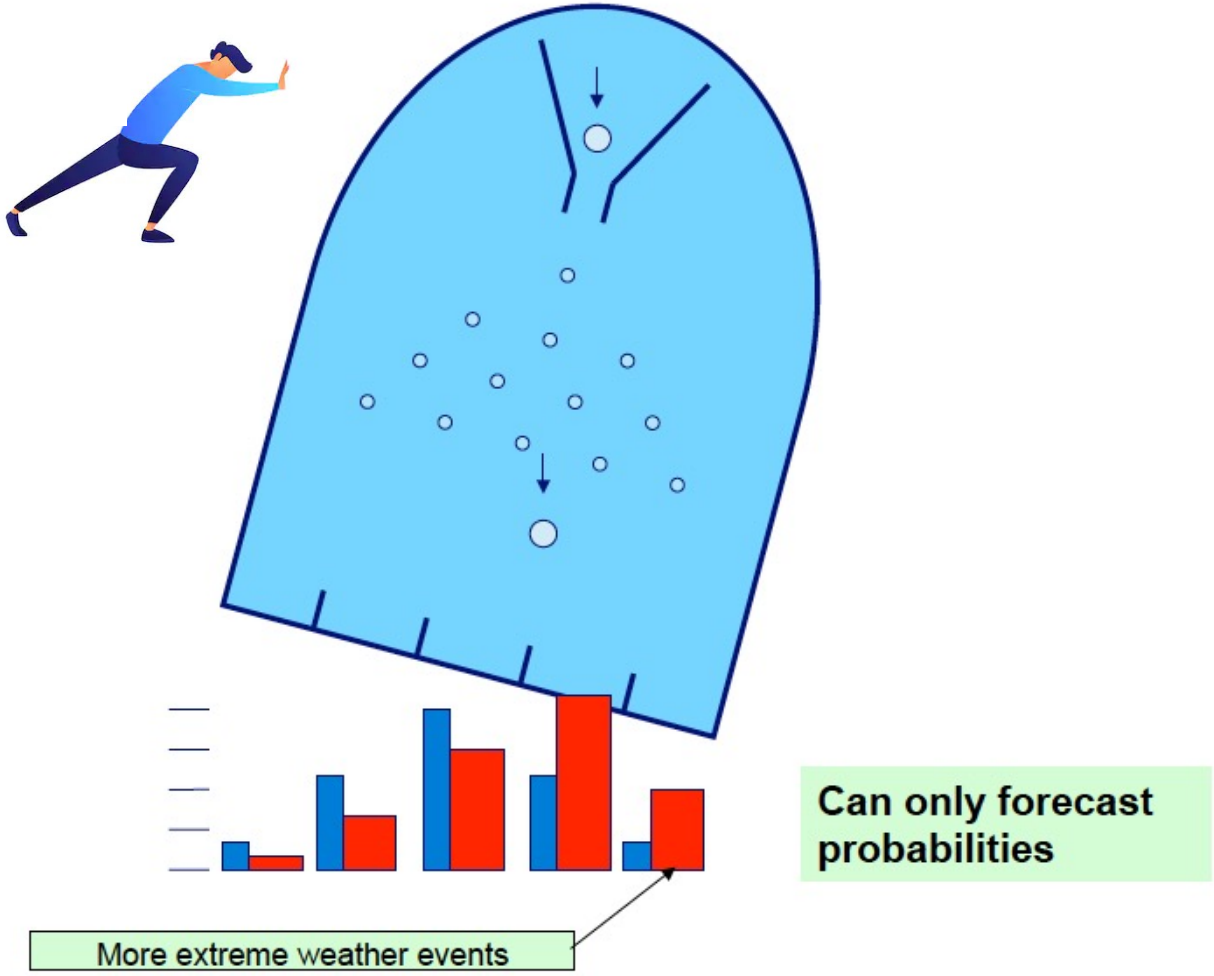
Greenhouse Gas Emissions



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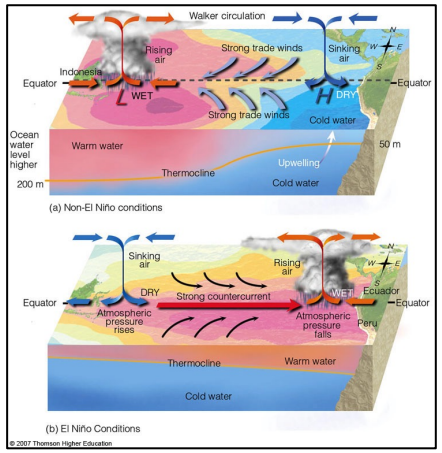
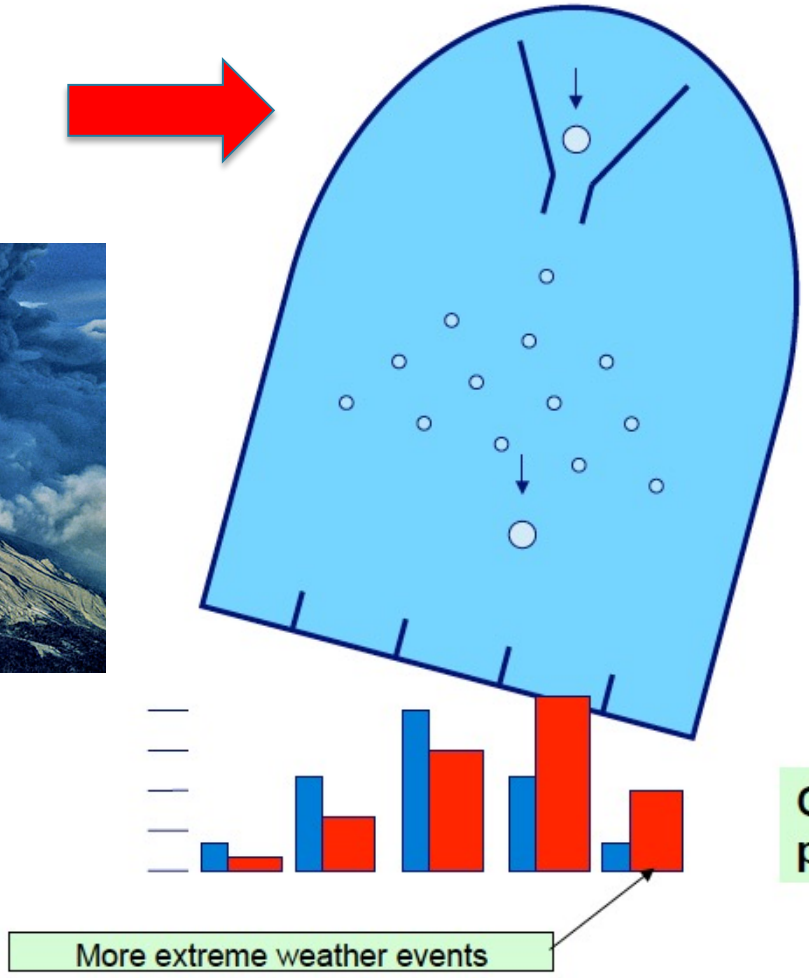
ENSO Cycles

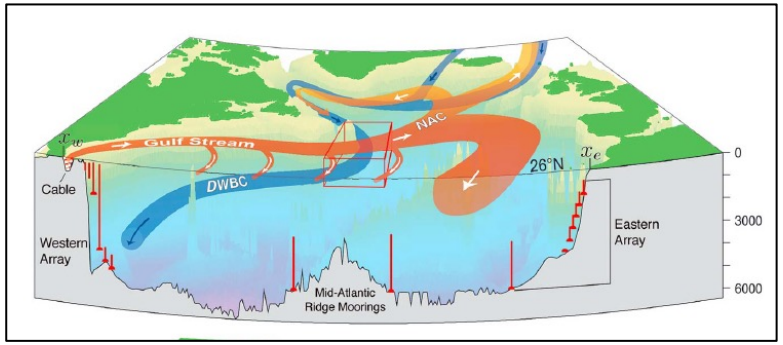


Volcanic Eruptions

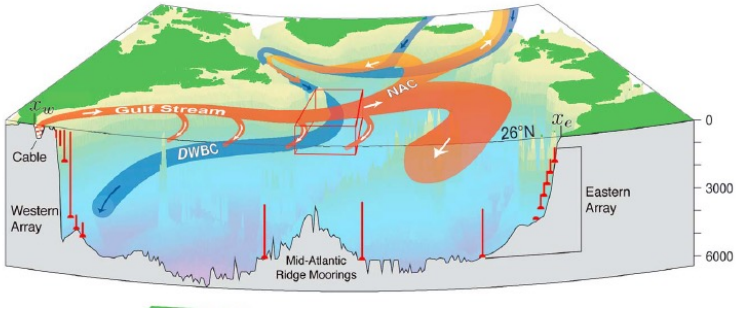


Can only forecast probabilities

Ocean Heat Transport

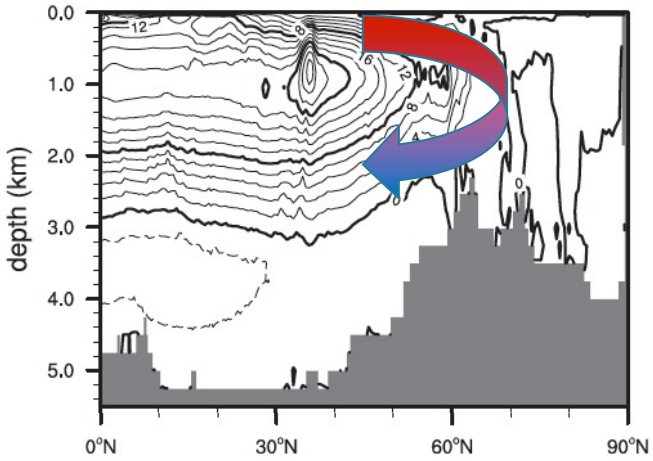


The Atlantic Ocean acts like a flywheel in the climate system

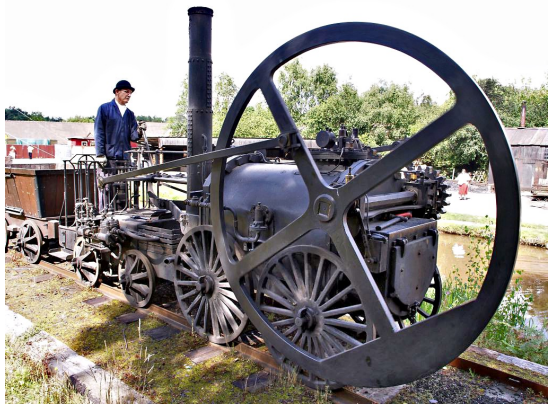


Side view

"AMOC" or "overturning circulation"



AMOC gets strong/weak on decadal timescales



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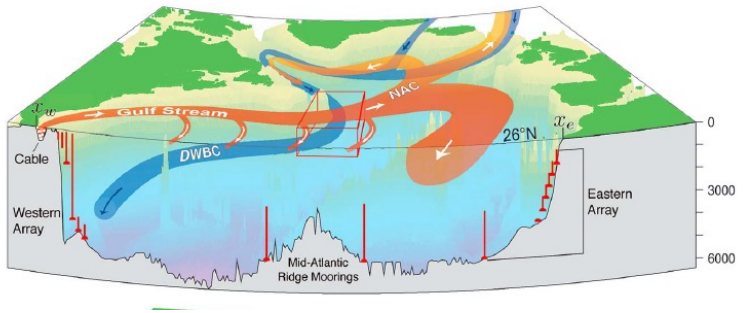


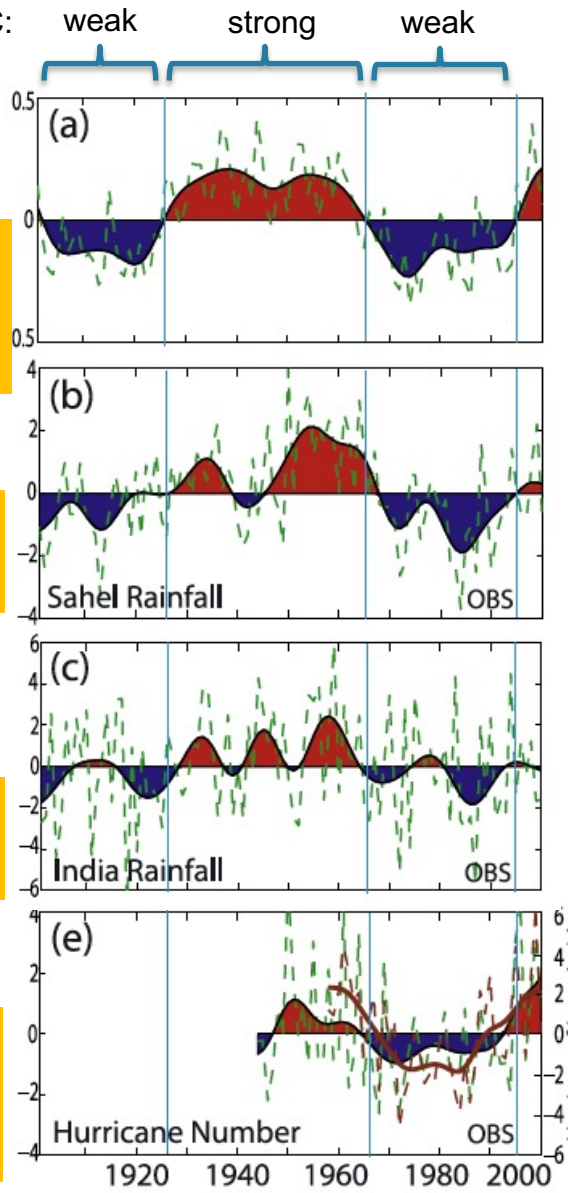
Changes in the strength of the Atlantic Ocean circulation

North Atlantic Ocean temperatures

Rainfall in Africa

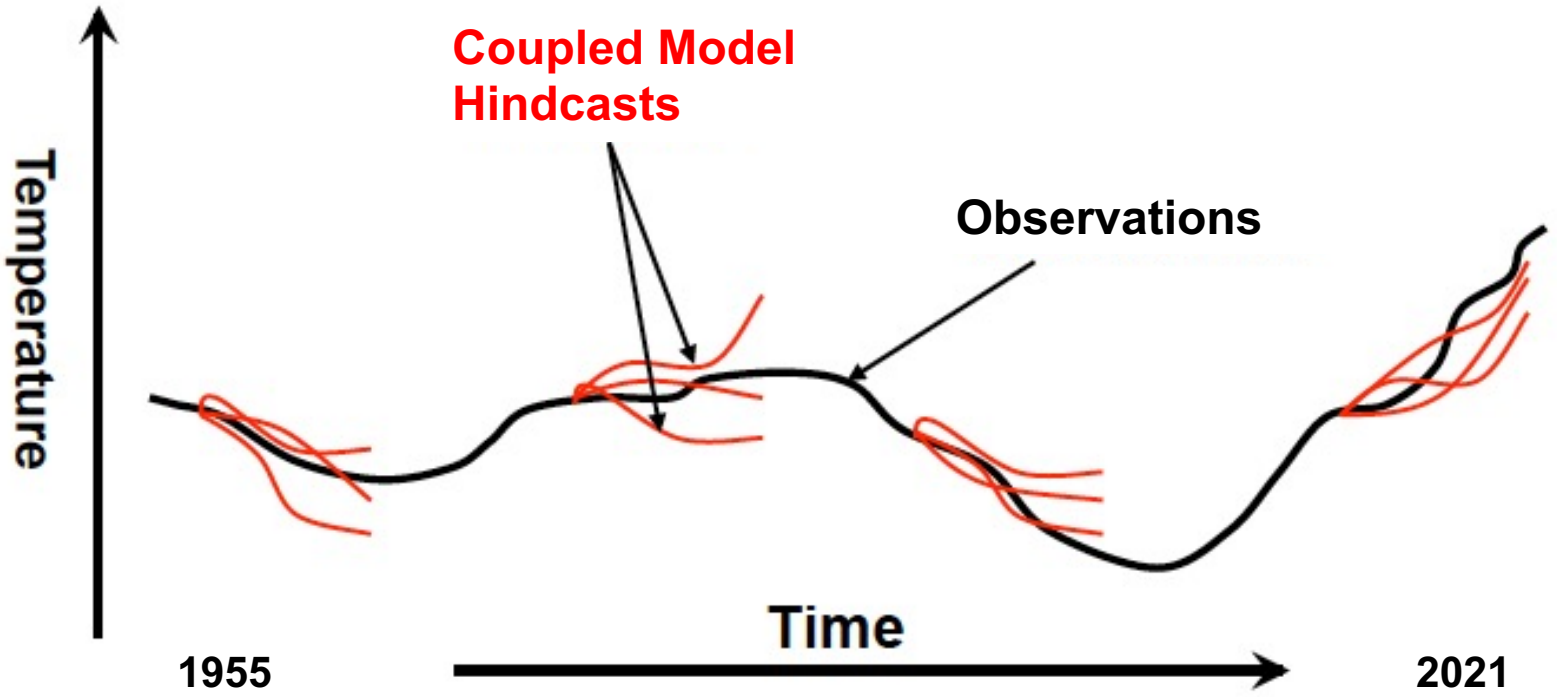
Rainfall in India

Atlantic Hurricane Activity



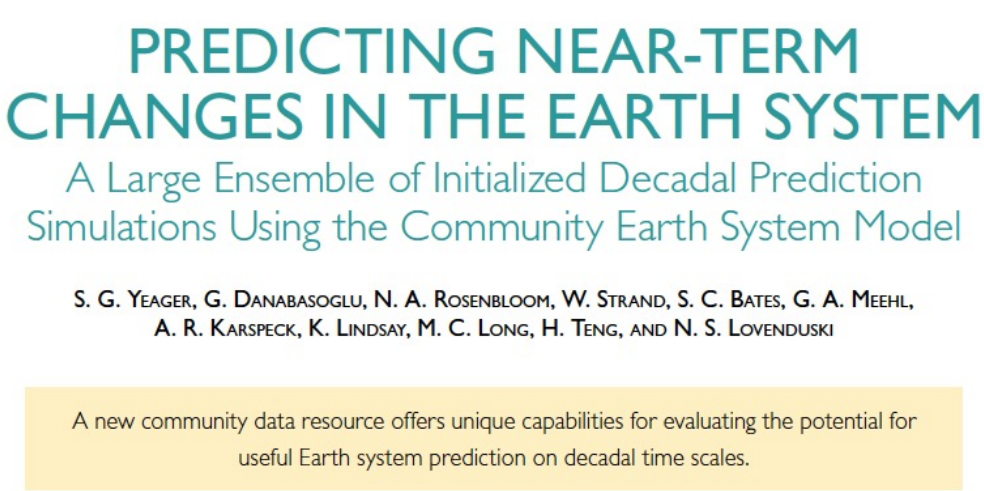
Plots from Zhang & Delworth (*GRL* 2006, doi:10.1029/2006GL026267)

How does decadal climate prediction work?



1. Generate an estimate of Earth's historical state (in particular, the oceans!) going back to the mid-20th century. Use this to initialize the global climate model.
2. Run many simulations of the climate model, starting from many different historical times.
3. Evaluate if the model is able to replicate the climate changes that were actually observed (ie., can it skillfully "hindcast" impactful changes that occurred in the past?).

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
- Includes ocean biogeochemistry
- Unprecedented statistical power for quantifying the impacts of initialization & ensemble size
- http://www.cesm.ucar.edu/projects/community-projects/DPLE/

- Made possible by multi-agency support:

The CESM Decadal Prediction Large Ensemble (CESM-DPLE)

Model	**CESM1.1**
atm	**CAM5** (FV 1°, 30 levels)
ocn	POP2 (1°, 60 levels) **with BGC**
ice	CICE4 (1°)
lnd	CLM4
UI ensemble	**40-member CESM twentieth-century Large Ensemble** (Kay et al. 2015)
Forcing	
through 2005	CMIP5 historical
from 2006 onward	CMIP5 **RCP 8.5**
Initialization	
method	Full field
atm	UI
ocn	**CORE*-forced FOSI**
ice	**CORE*-forced FOSI**
lnd	UI
Ensembles	
Ensemble size	**40**
Start dates	Annual; **1 Nov 1954–2015 (*N* = 62)**
Ensemble generation	Round-off perturbation of atm initial conditions
Simulation length	122 months

Standard resolution (1º) CESM

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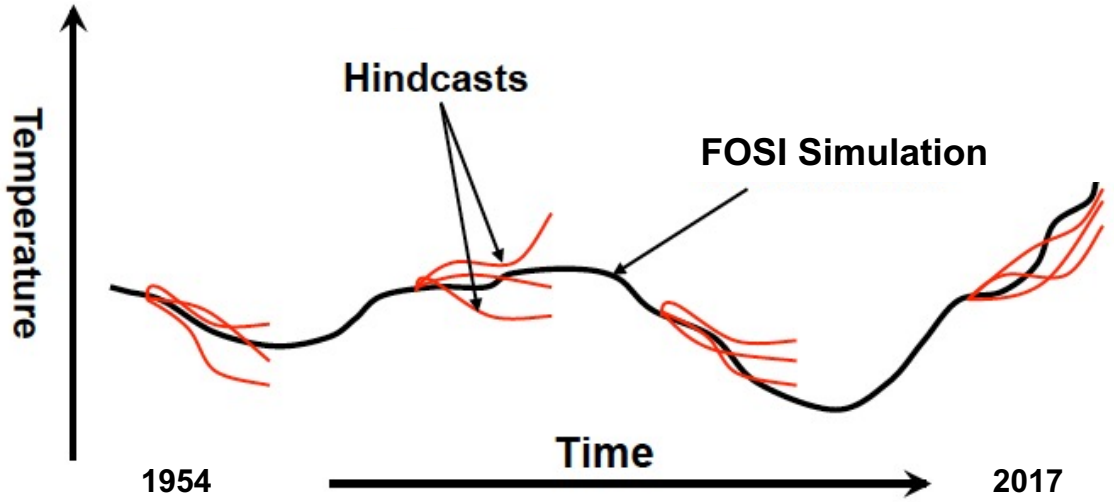

Initialize the ocean and sea-ice component models from a reanalysis-forced ocean+sea-ice (FOSI) simulation.

40-member ensemble hindcasts, initialized each Nov. 1st from 1954-2017.

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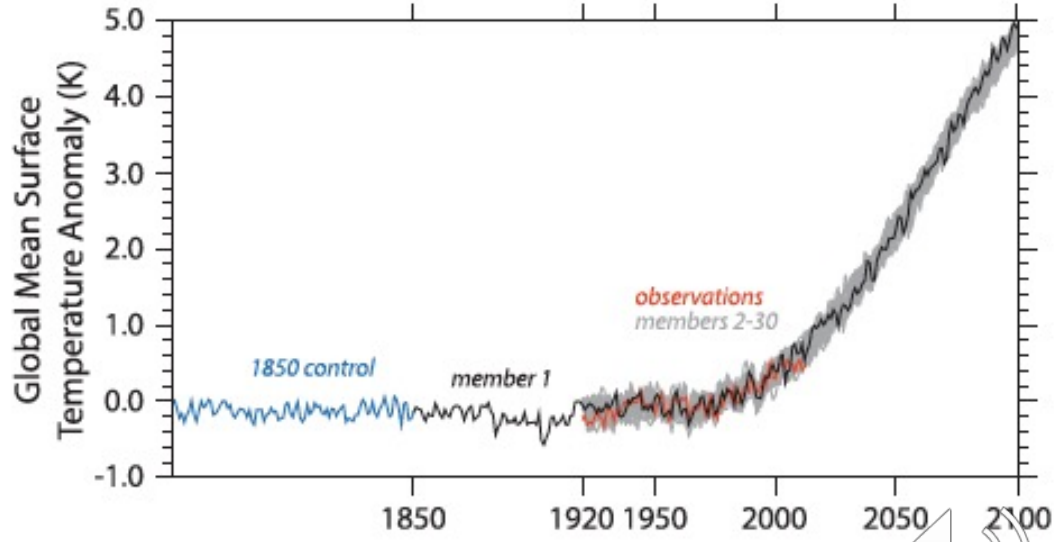
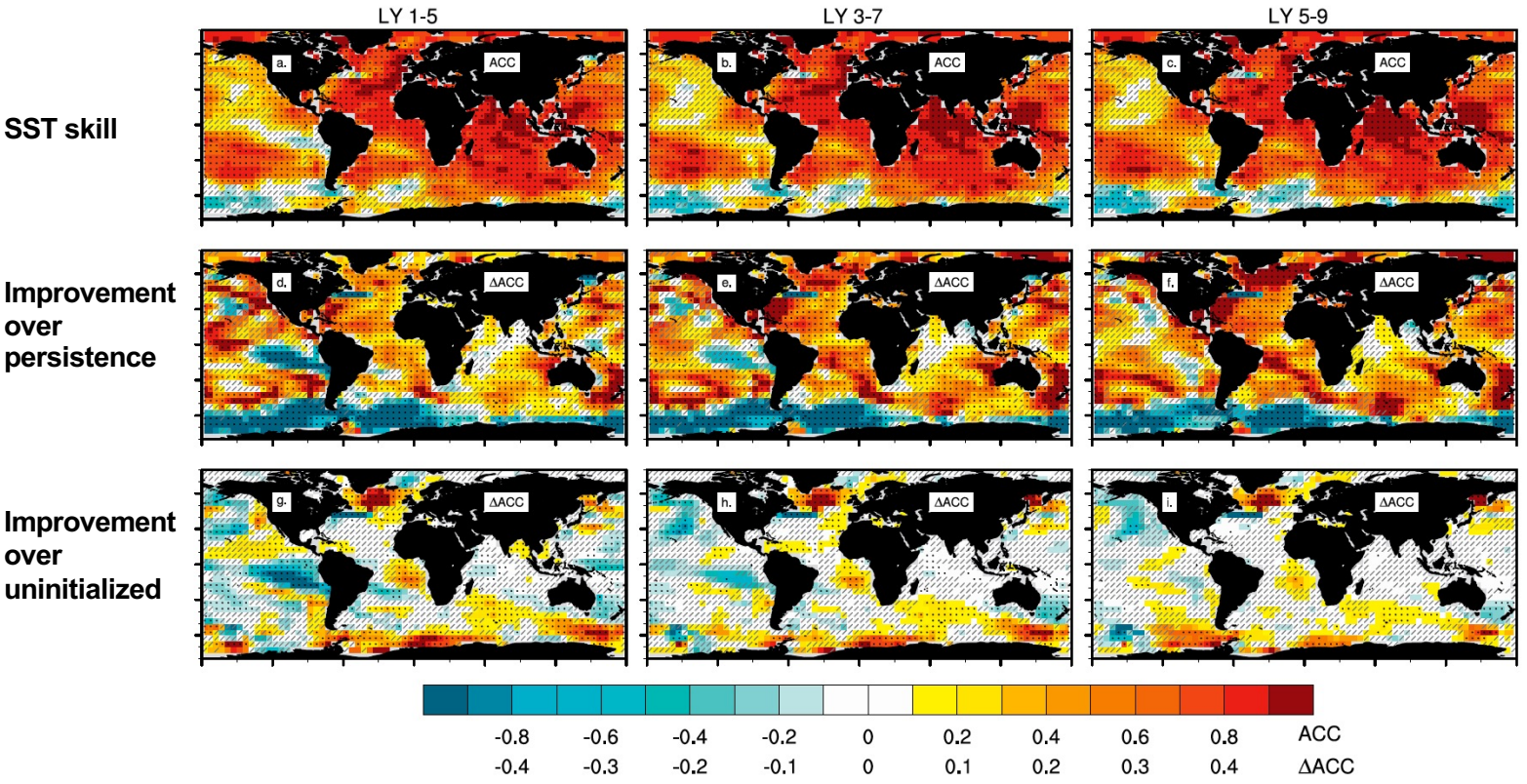
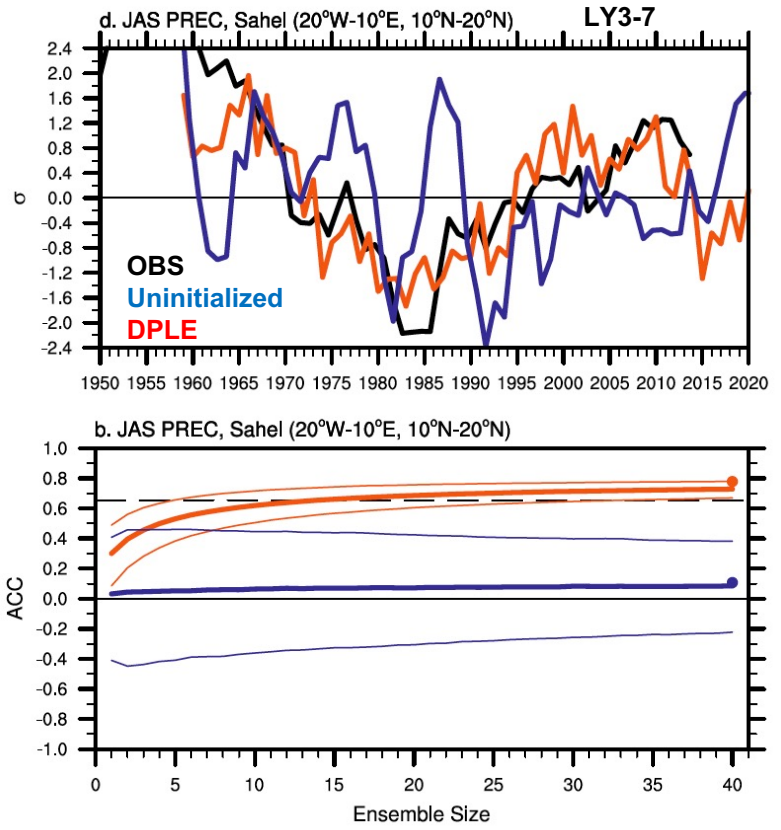
A parallel large ensemble of (uninitialized or UI) runs provides a benchmark for evaluating the impact of initialization



Skill at Predicting Sea Surface Temperature & Precipitation

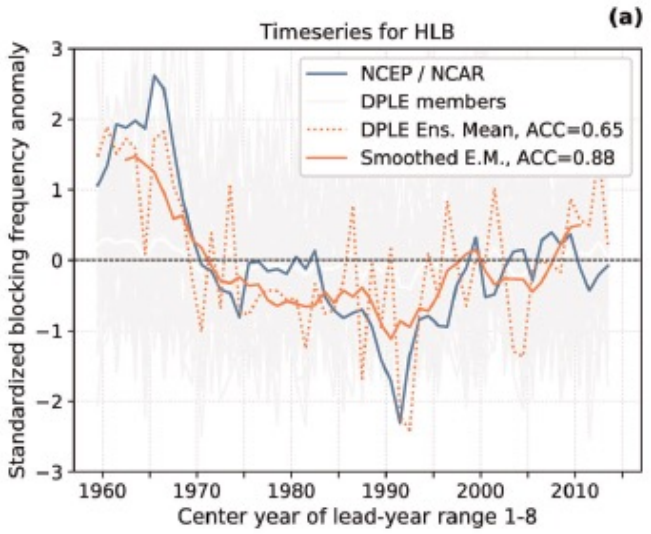


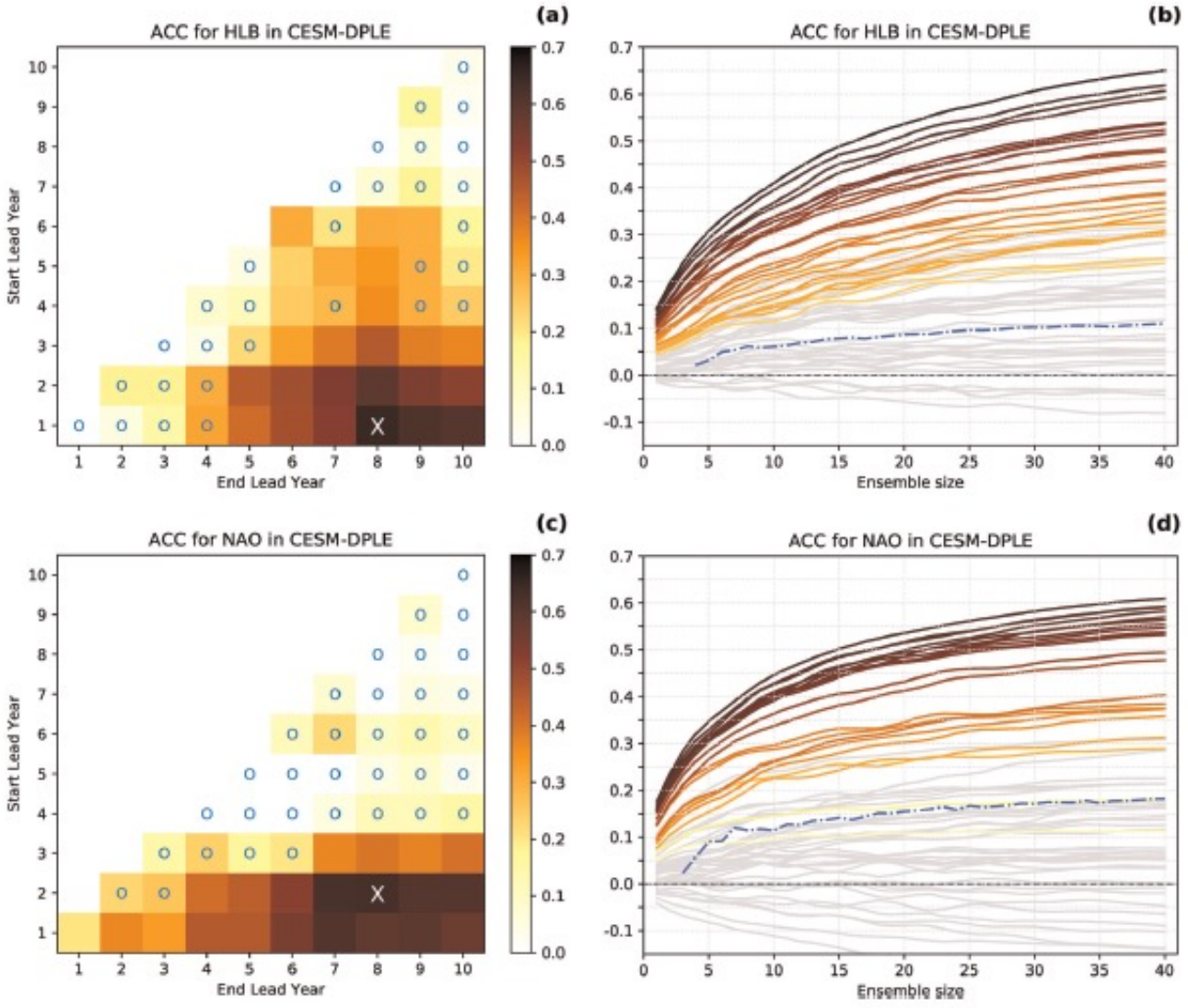


- High, long-lasting skill in N. Atlantic attributable to ocean initialization (for details, see Yeager 2020, doi:10.1007/s00382-020-05382-4)
- Noteworthy regional skill at predicting seasonal climate variations over land (e.g., African Sahel)
- Large Ensemble helps to maximize skill

Yeager et al. (2018, BAMS)

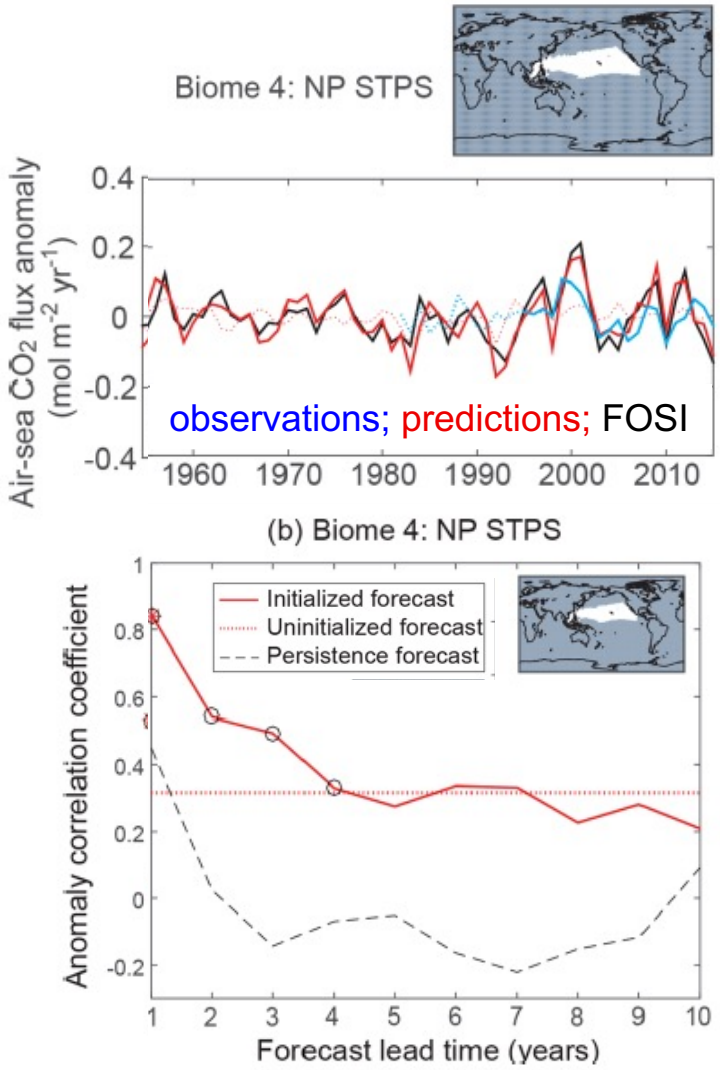
Decadal Prediction of Weather Extremes





Athanasiadis et al. (*npj Clim Atm Sci*, 2020, doi:10.1038/s41612-020-0[illegible]20-3)

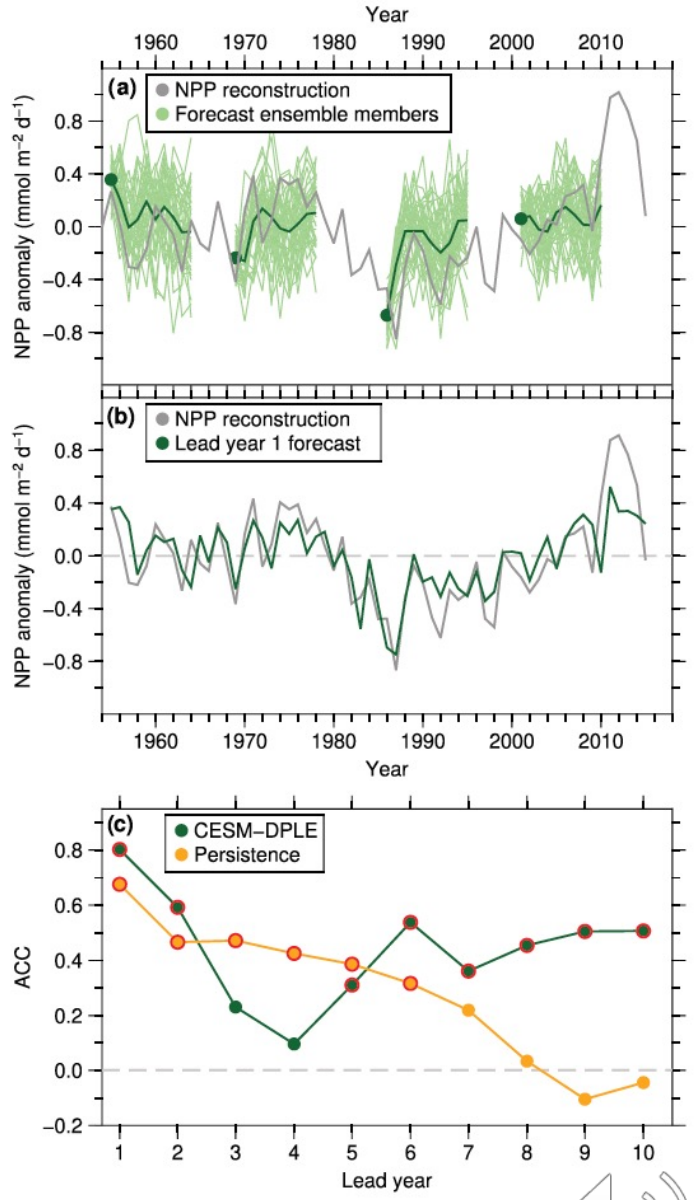
Predicting Ocean Biogeochemistry



- Multi-year skill in predicting air-sea CO_2 flux & Net Primary Productivity

← Lovenduski et al. (2019, *Earth Sys Dyn*, doi:10.1088/1748-9326/ab5c55)

➔ Krumhardt et al. (2020, *Glob Biogeochem Cyc*, doi:/doi.org/10.1029/2020GB006531)



Interested?

- **This is a relatively new field with many unanswered questions and outstanding challenges**
- **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)