# Interannual to Decadal Earth System Prediction at NCAR

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NCAR

**June 6, 2019**

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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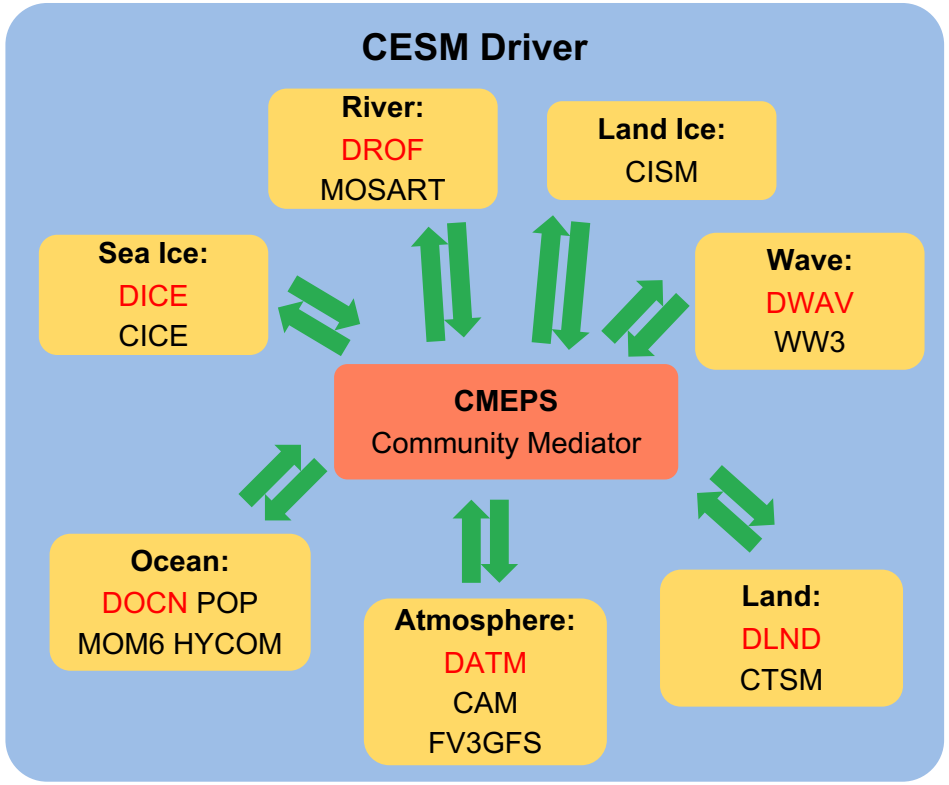
# OUTLINE

- What can NCAR contribute to a national ESPC effort?
- I2D prediction system design at NCAR
- Example results from initialized predictions using the Community Earth System Model (CESM)
- Outstanding challenges & future plans

# Key NCAR strengths relevant to ESPC:

- International leader in coupled climate & Earth system model development and application (the CESM project)
- Strong, synergistic ties to the university geoscience community
- Multidisciplinary scientific expertise in-house
- Multi-agency support for prediction research
- Emphasis on process understanding (well-founded predictions)
- Strong ocean modelling expertise ➔ extensive research experience in I2D ocean variability and historical ocean state reconstruction (i.e., generating relevant initial conditions)
- Growing expertise in coupled data assimilation
- Many promising results from preliminary explorations (since ~2011)

# Open Collaboration via Shared Infrastructure




- NCAR is embracing National Unified Operational Prediction Capability (NUOPC) standards
- CMEPS (Community Mediator for Earth Prediction Systems) is a flexible, NUOPC-based coupler that will enable sharing of model components across ESPC systems
- The next major release of CESM will include all NUOPC-compliant components. This aligns with ESPC's Common Model Architecture.
- Improved workflow with CIME (Common Infrastructure for Modeling the Earth)
- **Umbrella repository** on GitHub with links to all model components, driver, CMEPS, and workflow: https://github.com/ESCOMP/UFSCOMP/wiki/Milestone:-CMEPS-0.3

# I2D Prediction System Design

**NCAR contribution to the Decadal Climate Prediction Project (DCPP) of CMIP6:**

| | |
|---|---|
| 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** |
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| 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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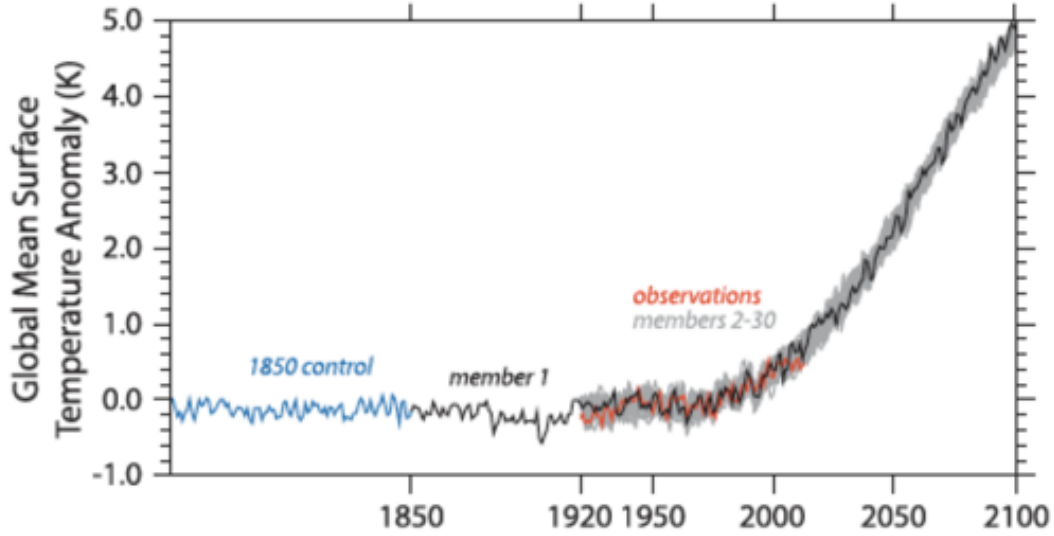
**Large ensemble of (uninitialized or UI) runs provides a benchmark for evaluating the impact of initialization**



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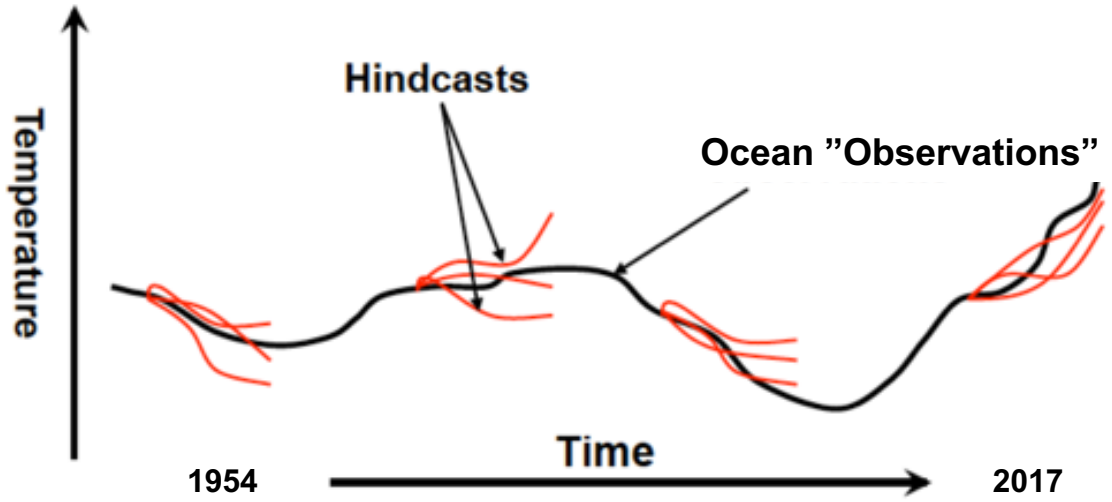


**Initialize the ocean and sea-ice component models from a reanalysis-forced ocean+sea-ice simulation.**

**40-member ensemble hindcasts, each year from 1954-2017.**

# The CESM Decadal Prediction Large Ensemble (CESM-DPLE)

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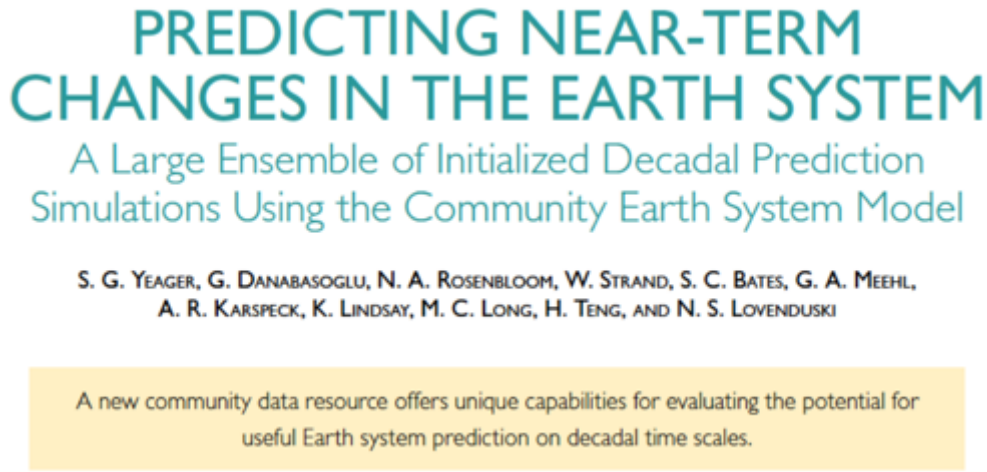
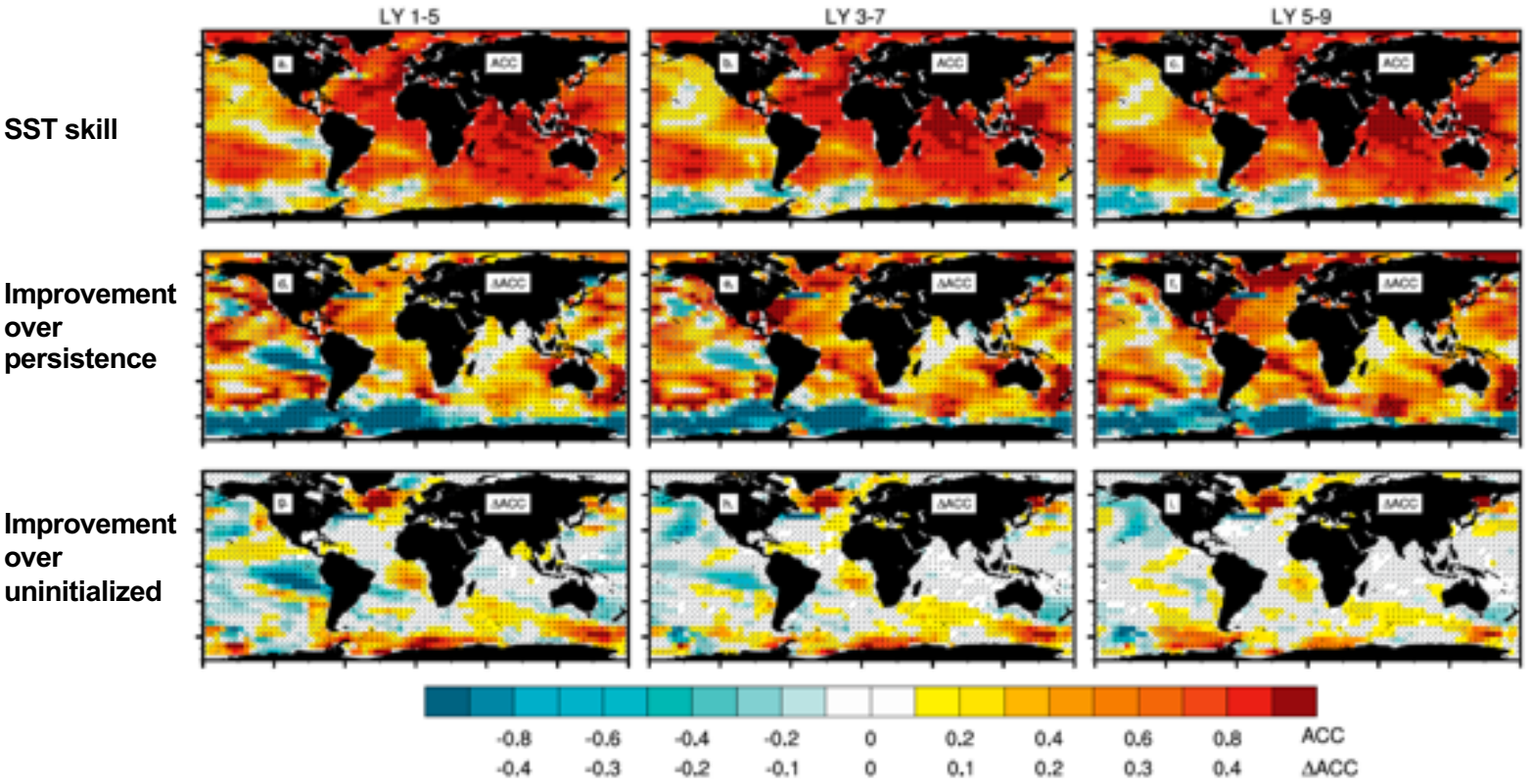


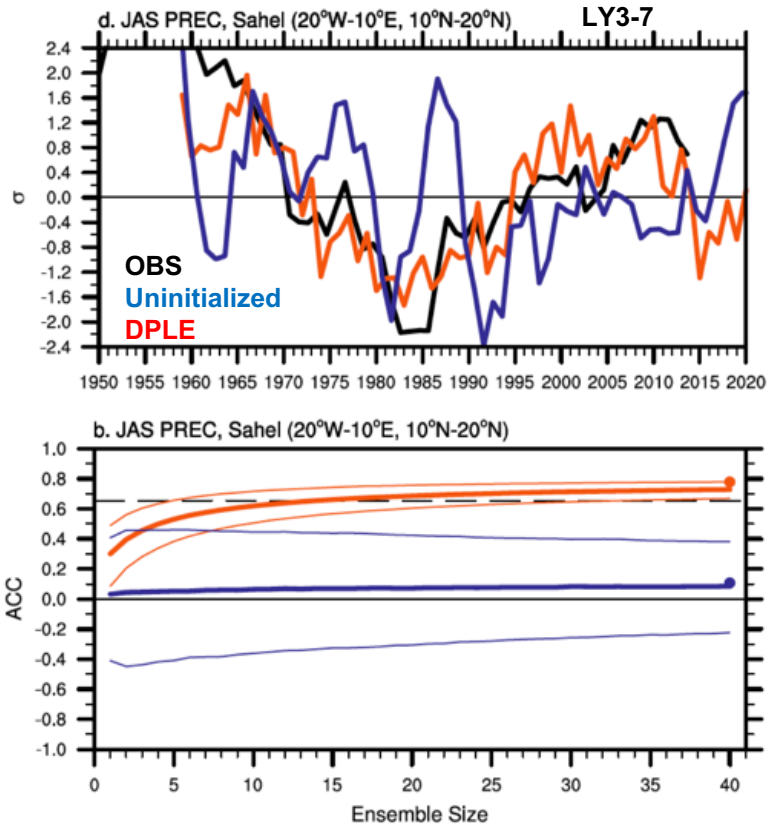

*BAMS*, September 2018

- ~26,000 sim-year experiment
- Prognostic 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:

# Predictions of Sea Surface Temperature & Precipitation over land

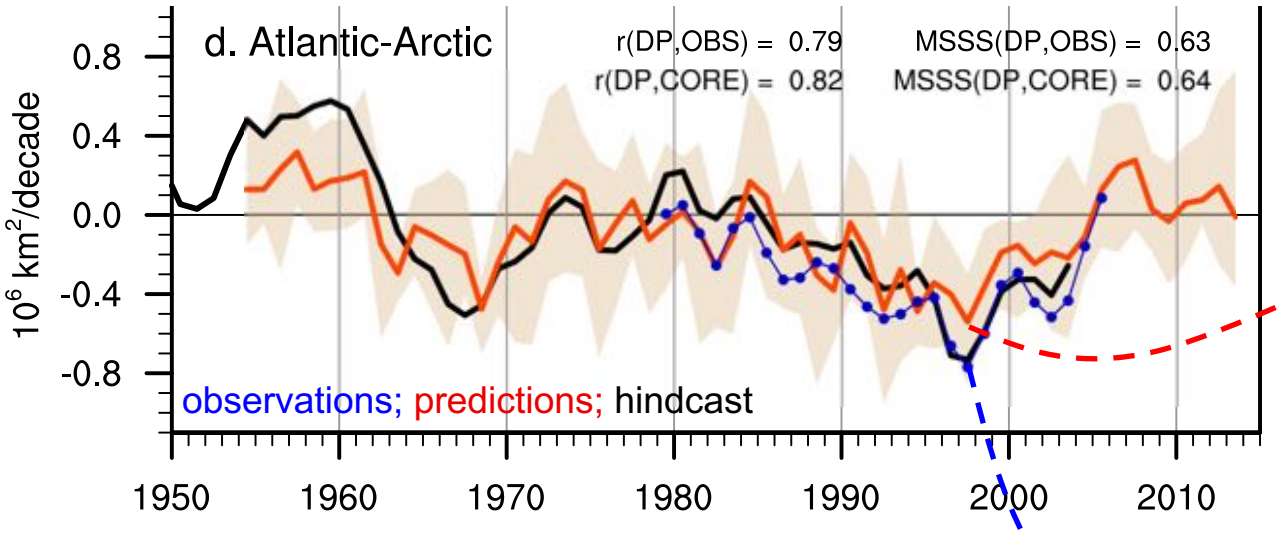


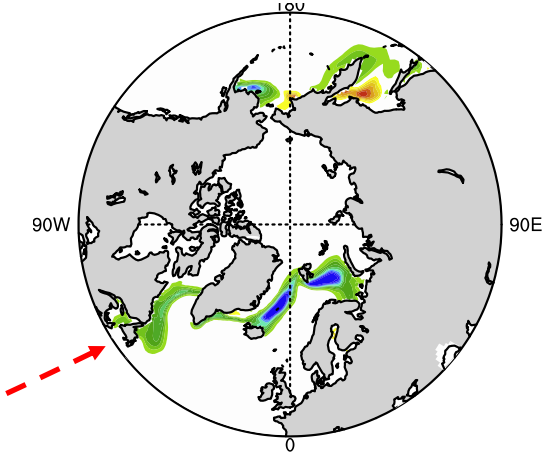

- High, long-lasting skill in N. Atlantic attributable to (ocean) initialization
- Some noteworthy skill at predicting seasonal climate variations over land (e.g., African Sahel)
- Low signal-to-noise in model ➔ larger ensembles improve skill

Yeager et al. (2018, BAMS)

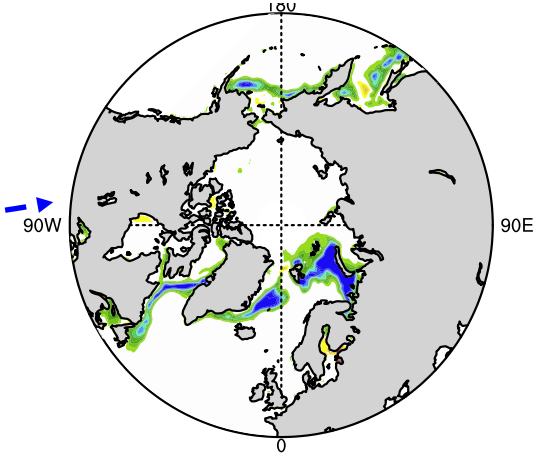
# Predictions of 10-year trends in Arctic Winter Sea Ice Extent




Predicted trend: 1997-2007



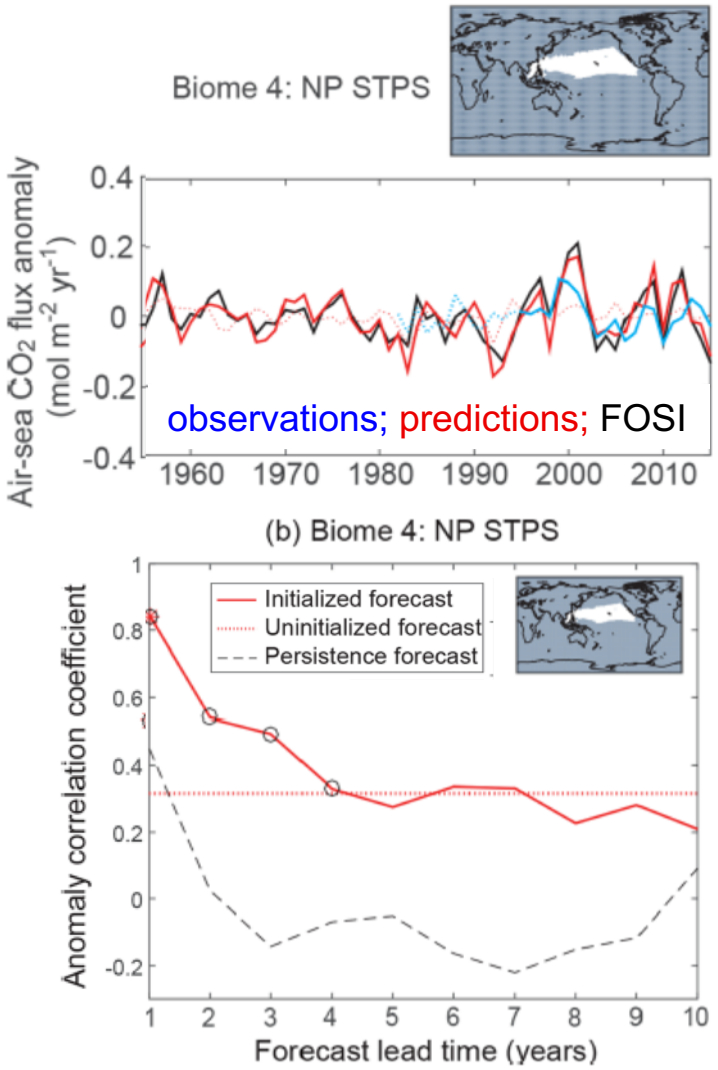

Observed trend: 1997-2007




- High N. Atlantic upper ocean heat content skill results in some predictability of decadal Arctic sea ice change

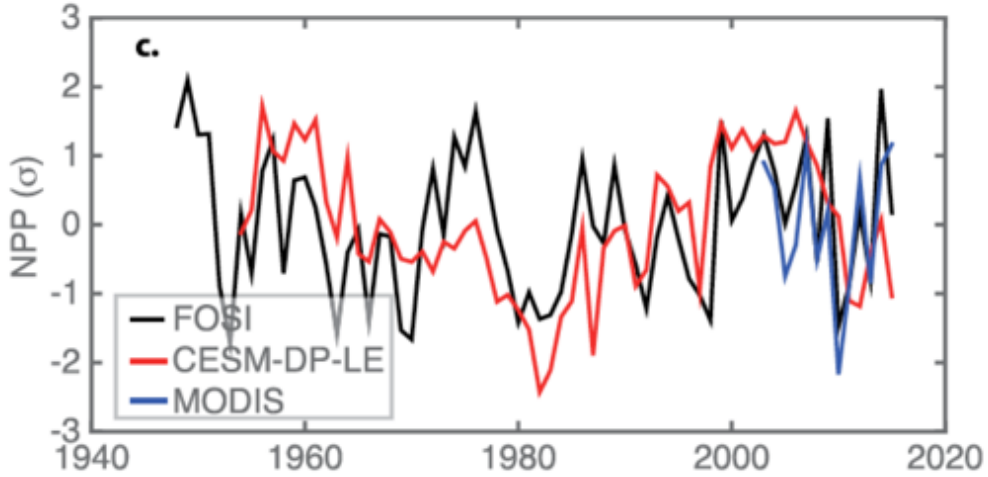
Yeager et al. (2015, GRL)

# Predicting Ocean Biogeochemistry




Lovenduski et al. (2019, Earth Sys Dyn)

**Net Primary Productivity in Canary Current Region**

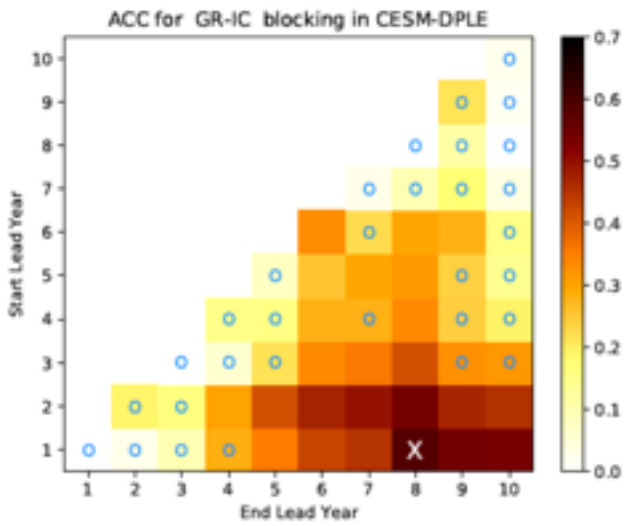


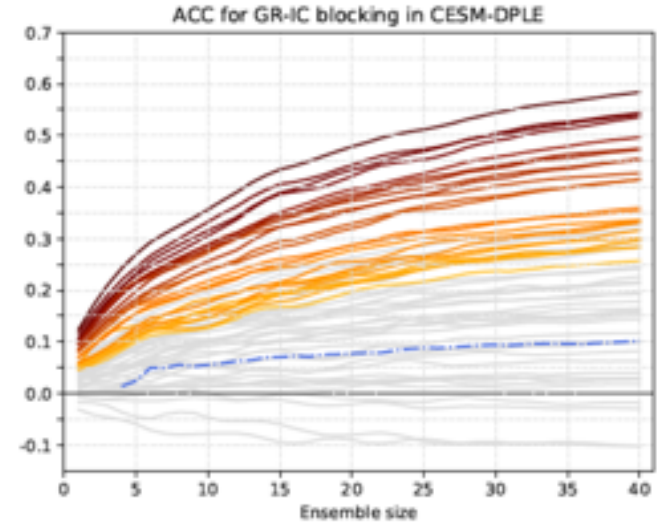

Yeager et al. (2018, BAMS)

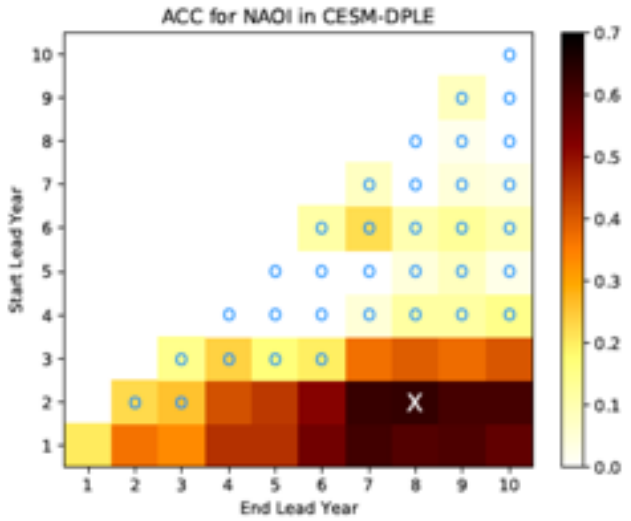
- Multi-year skill in predicting air-sea $CO_2$ flux & NPP
- Ongoing work to explore predictability of other components of Earth's carbon cycle & other ocean BGC fields

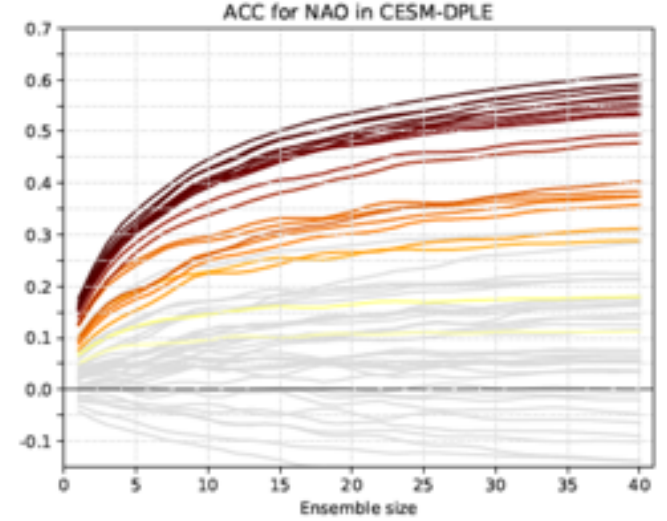
# Predicting Changes in Weather Extremes

- Unprecedented skill at predicting decadal variations in the frequency of winter blocking over Greenland & winter NAO, both of which have been linked to weather extremes over W. Europe
- Skill vs. ensemble size curve hints at potential for even greater predictability (with larger ensembles and/or improved models)




Athanasiadis et al. (2019, in prep)

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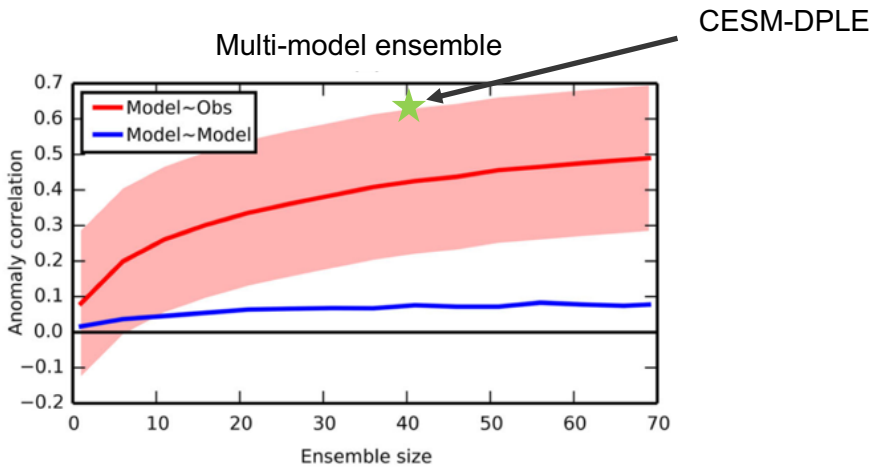
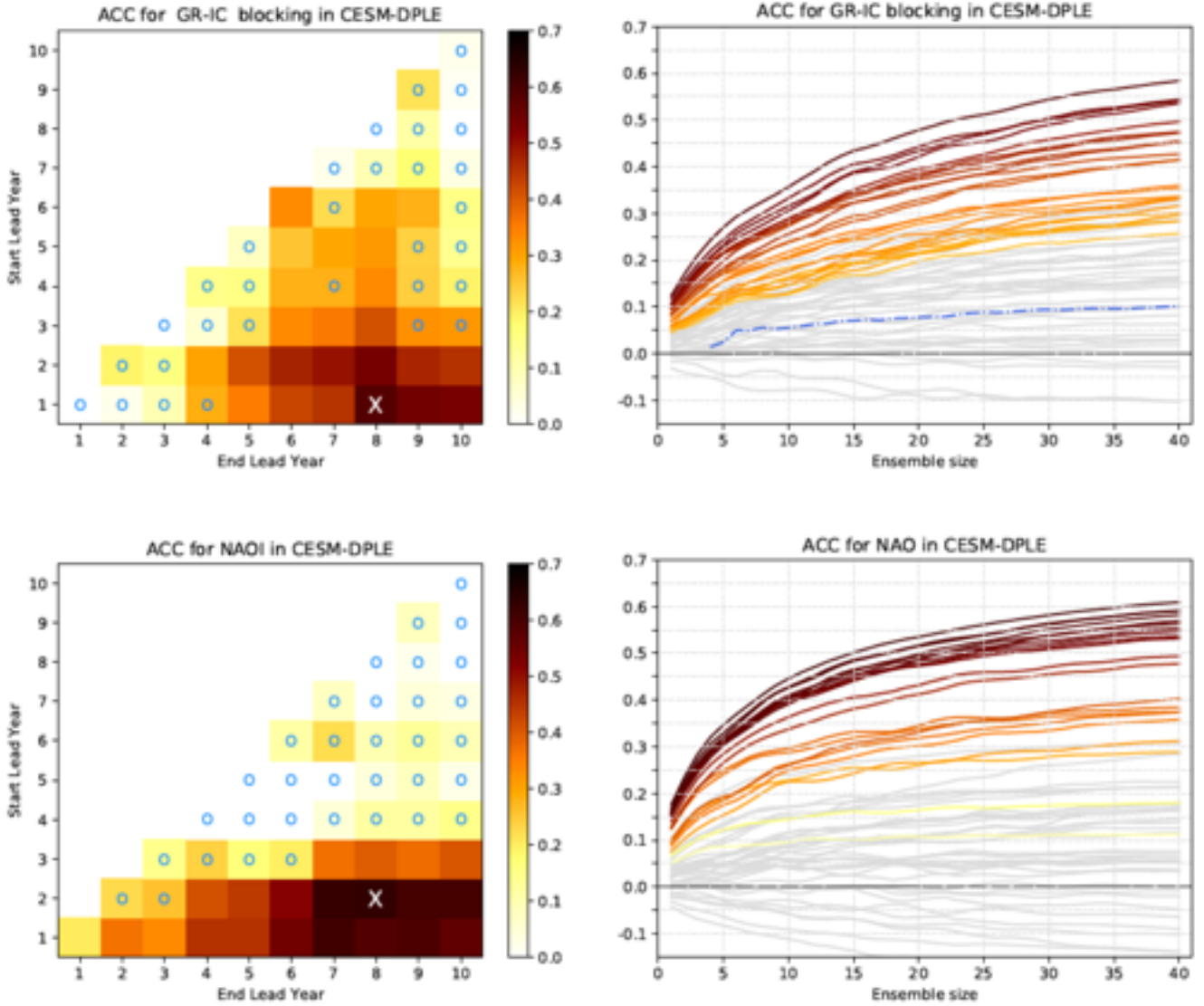



Smith et al. (2019, Clim Atm Sci)

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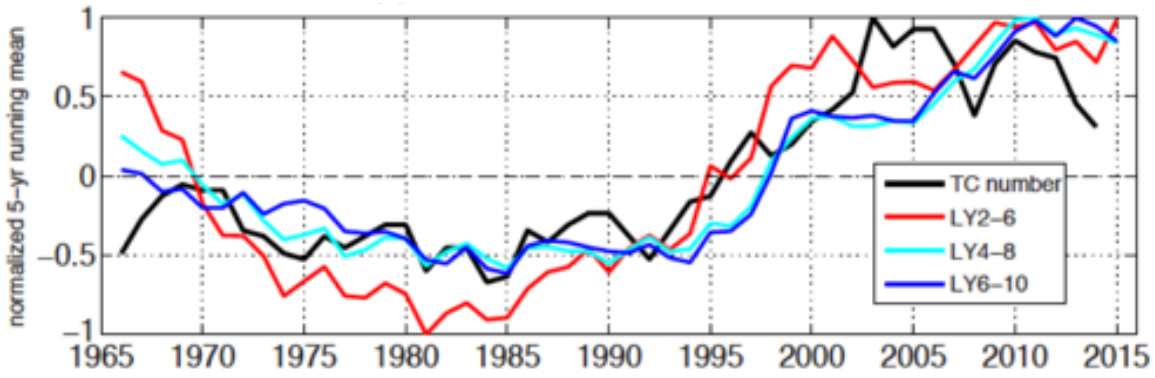
# Combined Dynamical-Statistical Predictions

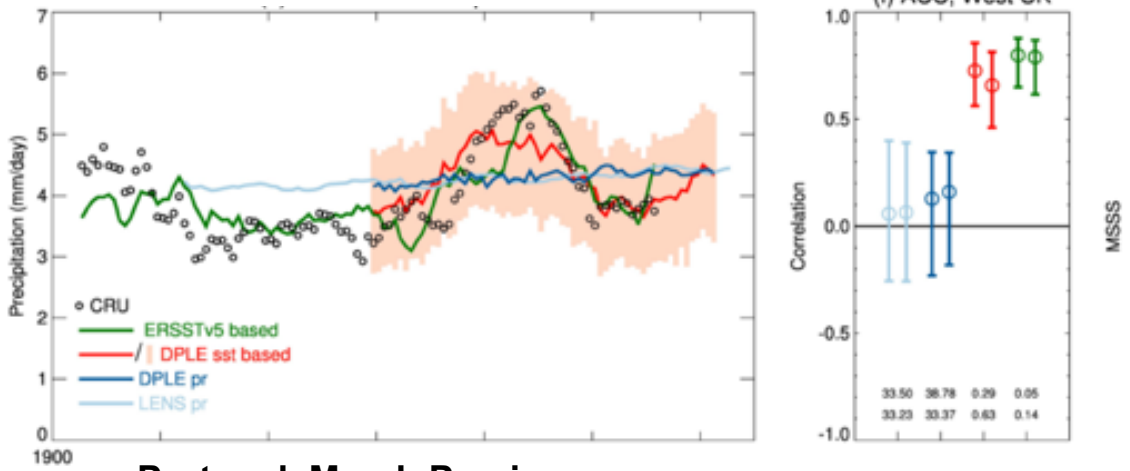
- **Combined dynamical-statistical approaches can be used to overcome the poor representation of some processes in the coarse model.**
- Skillful decadal prediction of winter precipitation over western Europe based on DPLE SST fields.
- Atlantic tropical cyclone predictions based on a GPI index computed from DPLE output (Hsu 2019).

**Atlantic Tropical Cyclone Activity**

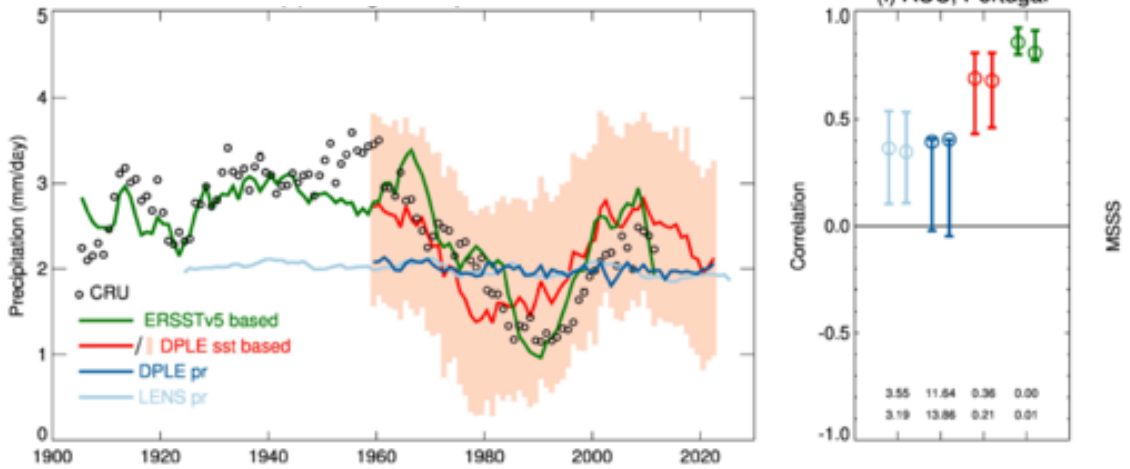



Hsu (2019, PhD thesis, Texas A&M)

**UK March Precip**




**Portugal March Precip**




Simpson et al. (2019, in press)

# Outstanding Challenges

- Model bias & drift in forecast-mode
- Initialization shock
- Ensemble generation
- Advancing state reconstructions (i.c.'s) to present-day to permit "real-time" forecasts
- Unstable & piecemeal funding
- Big Data issues
- Signal-to-noise "paradox"
- Insufficent understanding of DP system behavior & underlying predictability mechanisms

# Future Plans

- DPLE submission to CMIP6
- New I2D hindcast set using CESM2 & new ocean initialization method; compare with equivalent hindcast set run with E3SM (NCAR's DOE-funded CATALYST project)
- Explore coupled data assimilation for initializing I2D predictions
- High-resolution (ocean mesoscale eddy resolving & tropical cyclone permitting) initialized decadal prediction

# The CESM Decadal Prediction Large Ensemble: Forecasting decadal trends in the North Atlantic and Arctic

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