ESPWG Meeting, June 17, 2020

Decadal Prediction with CESM: Recent progress and Outstanding Challenges

Stephen Yeager
Climate and Global Dynamics Laboratory, NCAR

NCAR

NSF

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.

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

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, September 2018

- Latest decadal prediction data resource for the CESM community
- ~26,000 sim-year experiment
- CESM contribution to the Decadal Climate Prediction Project (DCPP) of CMIP6
- One of only a handful of CMIP6 DP systems to include prognostic ocean biogeochemistry
- Recently extended to include initializations through 2017 (no further updates planned)
- Data available from :
  - http://www.cesm.ucar.edu/projects/community-projects/DPLE/
  - CMIP6 data archive (ESGF)

- Made possible by multi-agency support:

- High global decadal prediction skill for SST/SAT, much of which is attributable to external forcing
- Skill improvement over uninitialized ensemble most evident for detrended variability
- Significant SST skill enhancement from initialization in subpolar Atlantic, but widespread skill degradation from initialization in the Pacific
- Clear evidence of SAT/PREC skill enhancement from initialization (e.g. summer PREC in Sahel), but with complex dependence on region/season/lead time
- Large ensemble size enhances skill
- Evidence of signal-to-noise paradox in decadal PREC

- What more have we learned about CESM-DPLE over the past 2 years?

PREDICTING NEAR-TERM CHANGES IN THE EARTH SYSTEM

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

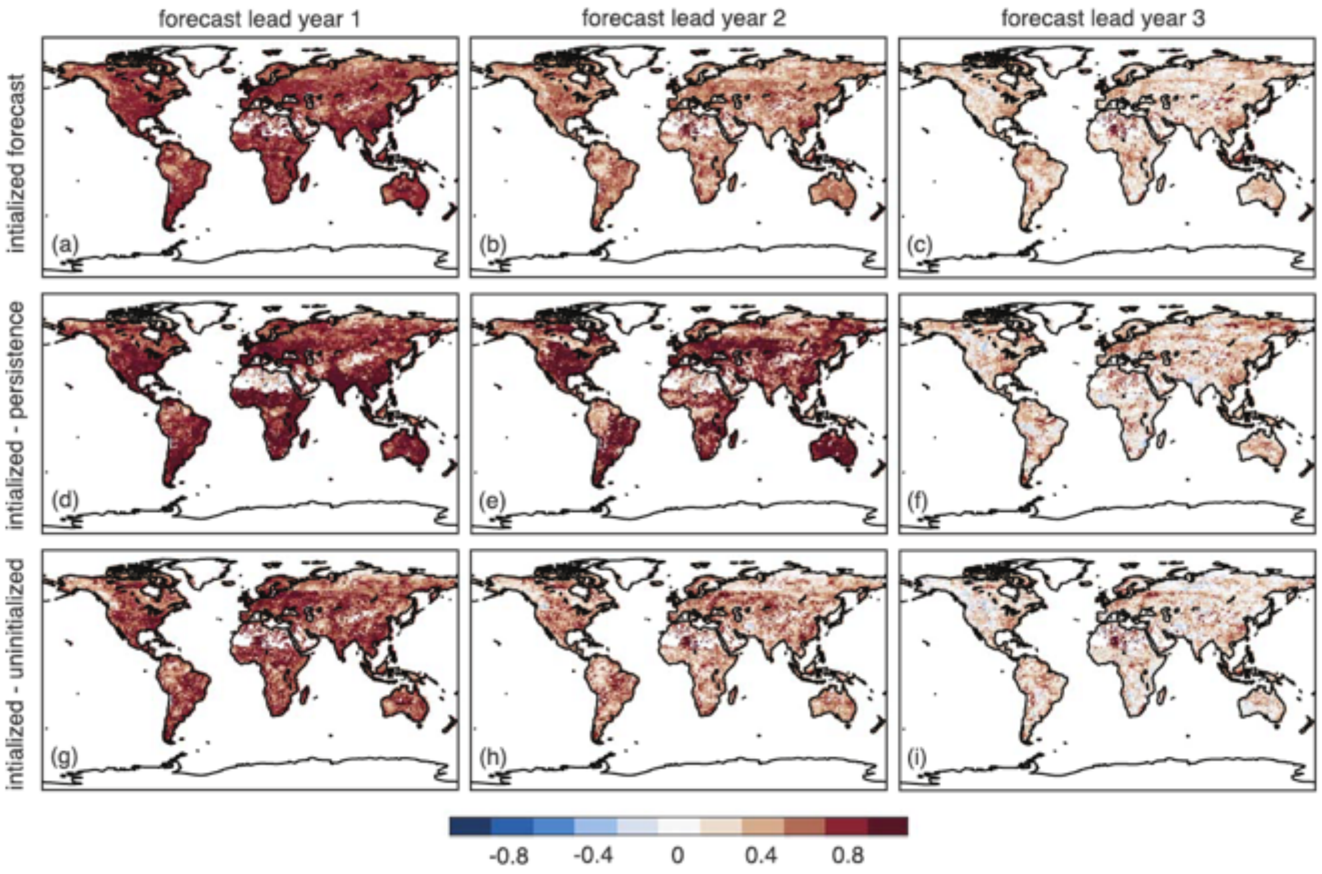
S. G. Yeager, G. Danabasoglu, N. A. Rosenbloom, W. Strand, S. C. Bates, G. A. Meehl, A. R. Karspeck, K. Lindsay, M. C. Long, H. Teng, and N. S. Lovenduski

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

BAMS, September 2018

Multiyear Ocean BGC & Carbon Cycle Predictability

Net Ecosystem Production Skill:



Lovenduski et al. (2019b)

CESM-DPLE used to demonstrate (potential) predictability of:

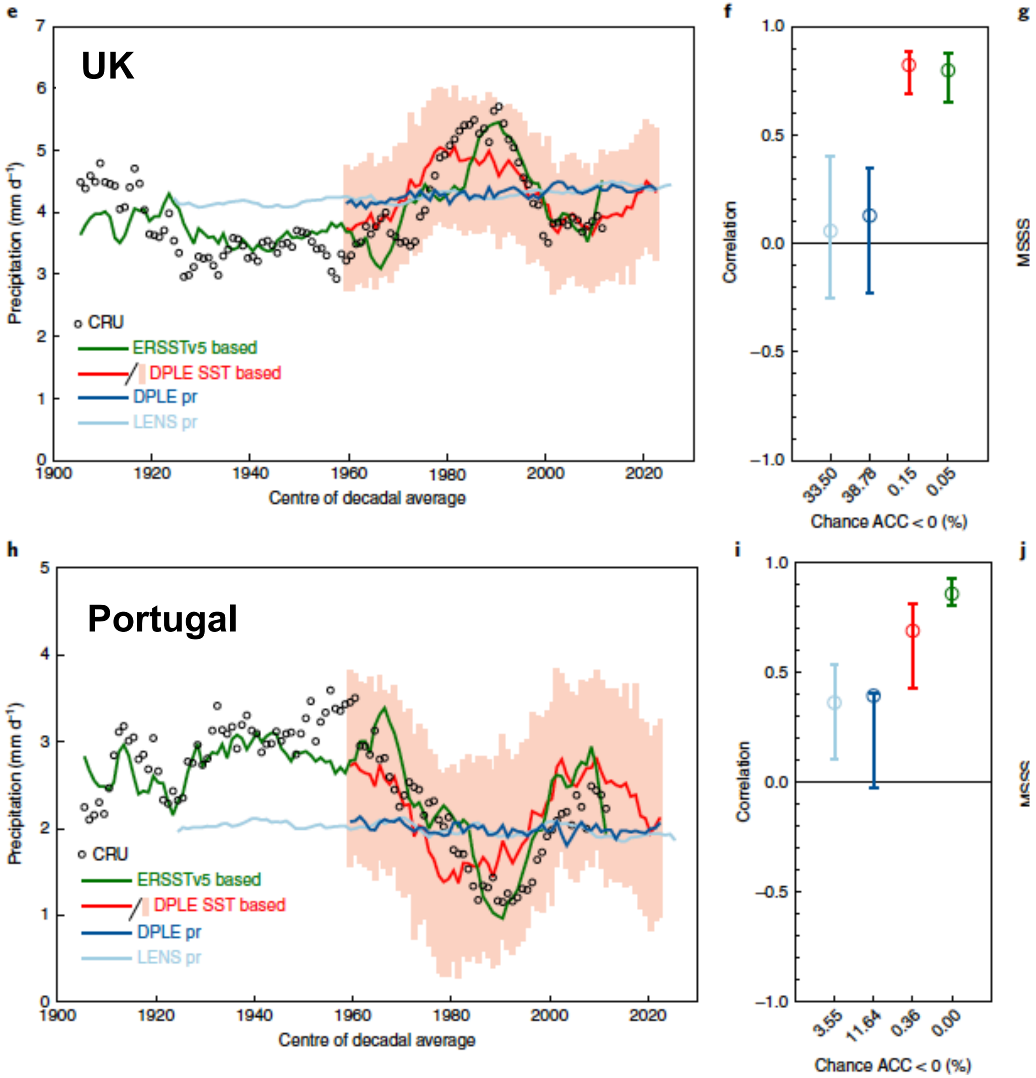
- ocean carbon uptake (Lovenduski et al. 2019a)
- terrestrial carbon fluxes (Lovenduski et al. 2019b)
- ocean acidification in the California Current (Brady et al. 2020)
- ocean net primary production (Krumhardt et al. 2020)

- Highlights the value of FOSI initialization for exploring potential predictability of poorly observed ocean fields (for which data assimilation may not be a viable option)

- Highlights the need to upgrade to CLM5 and realistic land initialization in future CESM initialized prediction efforts (including decadal)

Decadal Predictability in the Atlantic Sector

March Decadal Precipitation Skill:



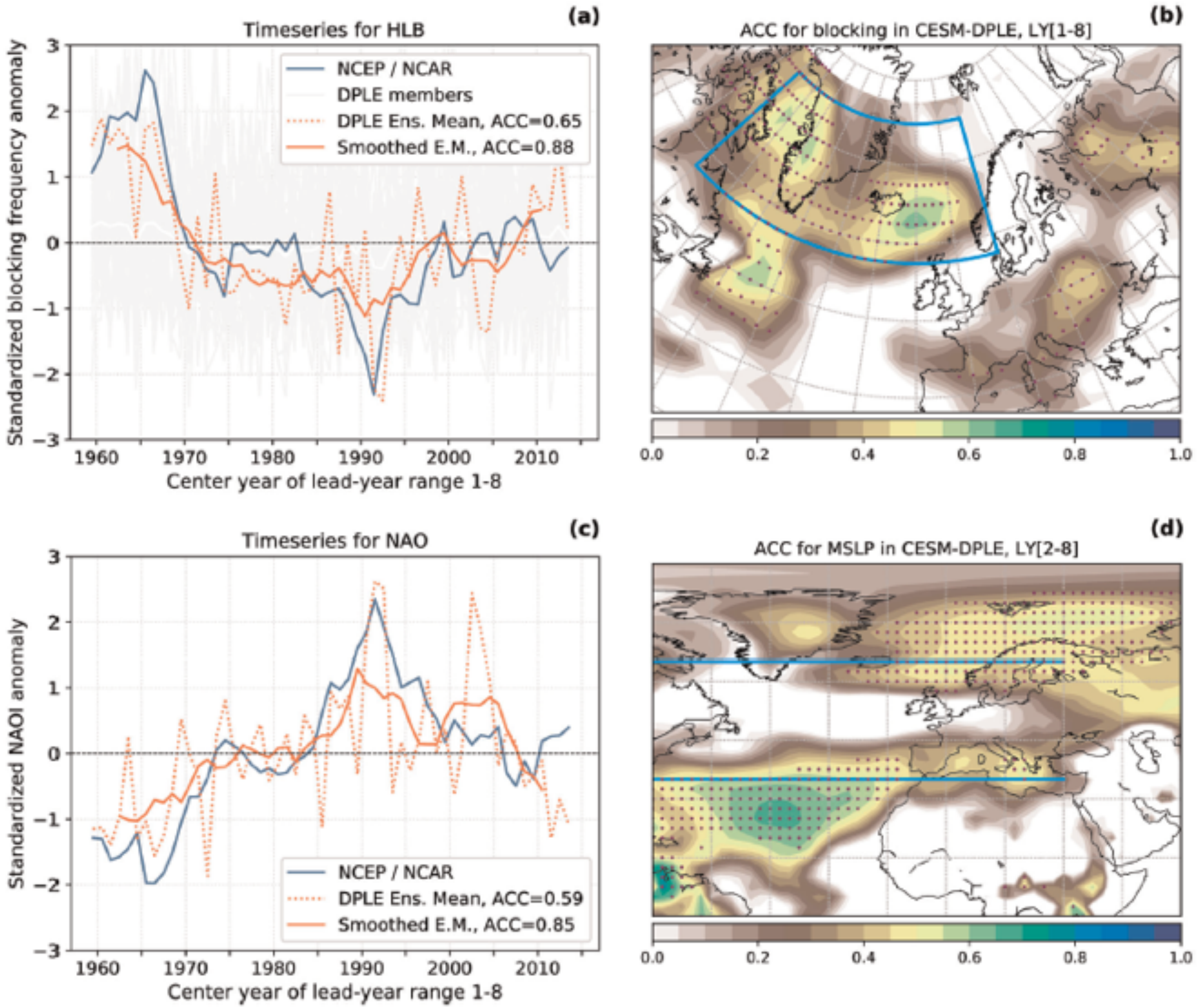
- Strong observed link between multidecadal fluctuations in N. Atlantic jet & N. Atlantic SST was used to show that a combined dynamical-statistical prediction of late-winter European precipitation can be skillful at decadal lead times

- Demonstrates the potential to enhance prediction system skill (circumvent model error) through novel approaches

- Hints at anemic atmospheric response to skillfully predicted SST

Simpson et al. (2019)

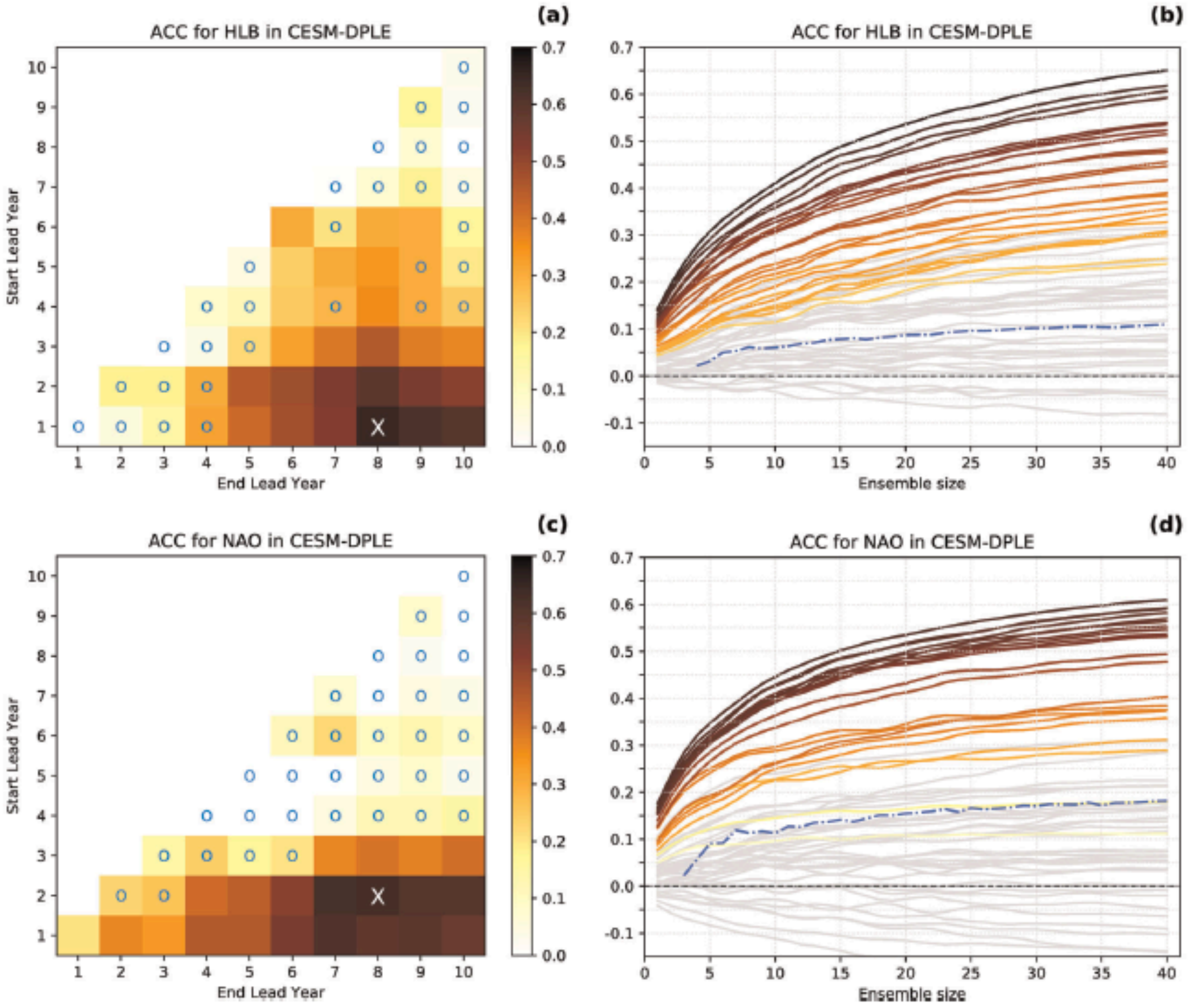
Decadal Predictability in the Atlantic Sector



- Skillful decadal prediction of winter (DJFM) subpolar Atlantic (a) blocking frequency and (c) NAO

Athanasiadis et al. (2020)

Decadal Predictability in the Atlantic Sector

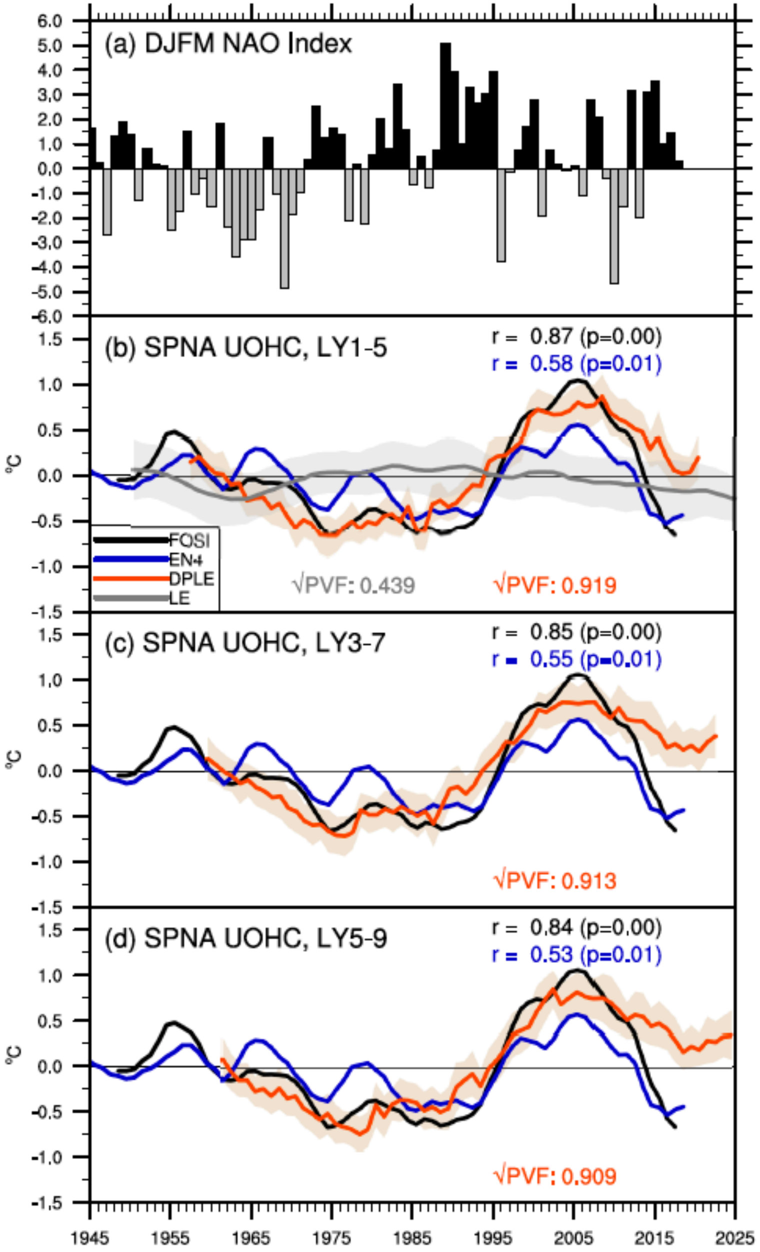


- Skillful decadal prediction of winter (DJFM) subpolar Atlantic (a) blocking frequency and (c) NAO
- Skill maximizes for lead ranges (LY1-8 for HLB, LY2-8 for NAO) that isolate decadal variability
- Skill increases with ensemble size and has not saturated at 40
- Evidence of much lower predictable variance component in DPLE than in observations (signal-to-noise paradox)
- Highlights potential for higher prediction skill by enhancing atmospheric signal variance (or, just increasing ensemble size)

Athanasiadis et al. (2020)

Decadal Predictability in the Atlantic Sector

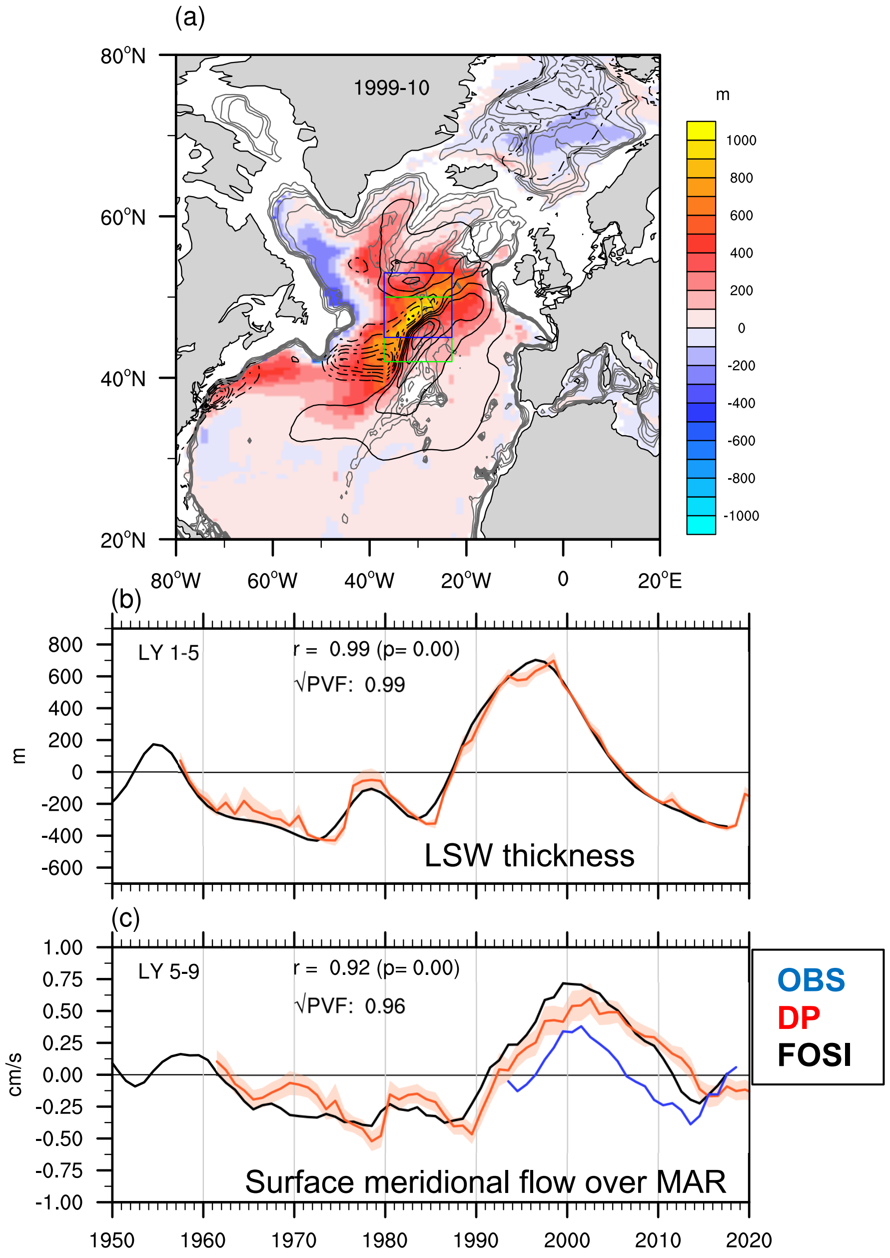
- High prediction skill for upper ocean heat content (UOHC) in the subpolar North Atlantic (SPNA) is stable out to 10 year lead times



Yeager (2020)

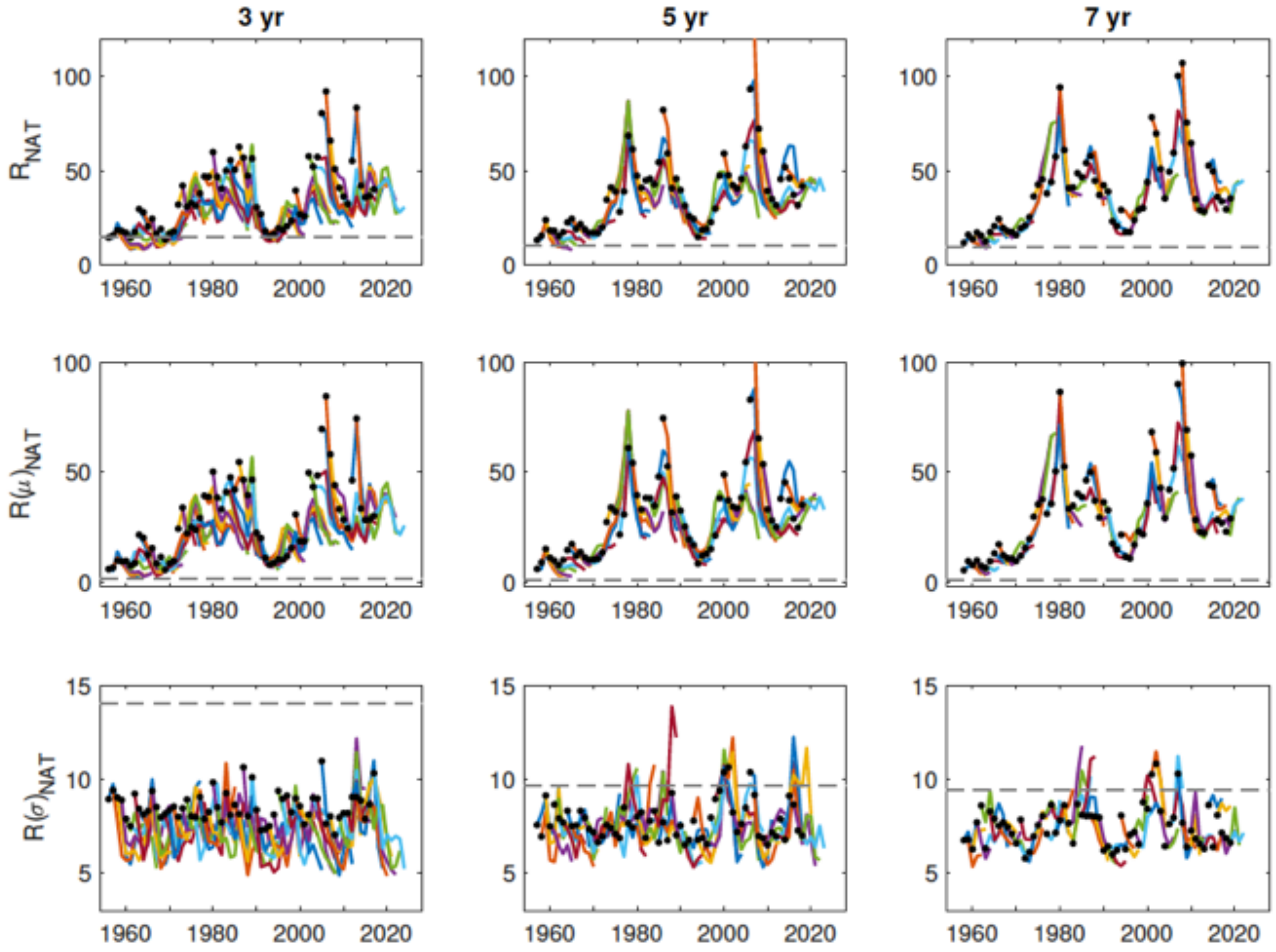
Decadal Predictability in the Atlantic Sector

- High prediction skill for upper ocean heat content (UOHC) in the subpolar North Atlantic (SPNA) is stable out to 10 year lead times
- The fundamental reservoir of ocean memory in the Atlantic is Labrador Sea Water (LSW) thickness, which drives highly predictable, decadal, near-surface advective heat convergence anomalies in the vicinity of the Mid-Atlantic Ridge (MAR).
- Suggests that (unobserved) deep ocean variations are key to successful Atlantic decadal prediction
- Highlights the value of FOSI initialization for understanding predictability mechanisms



Yeager (2020)

State-dependent predictability

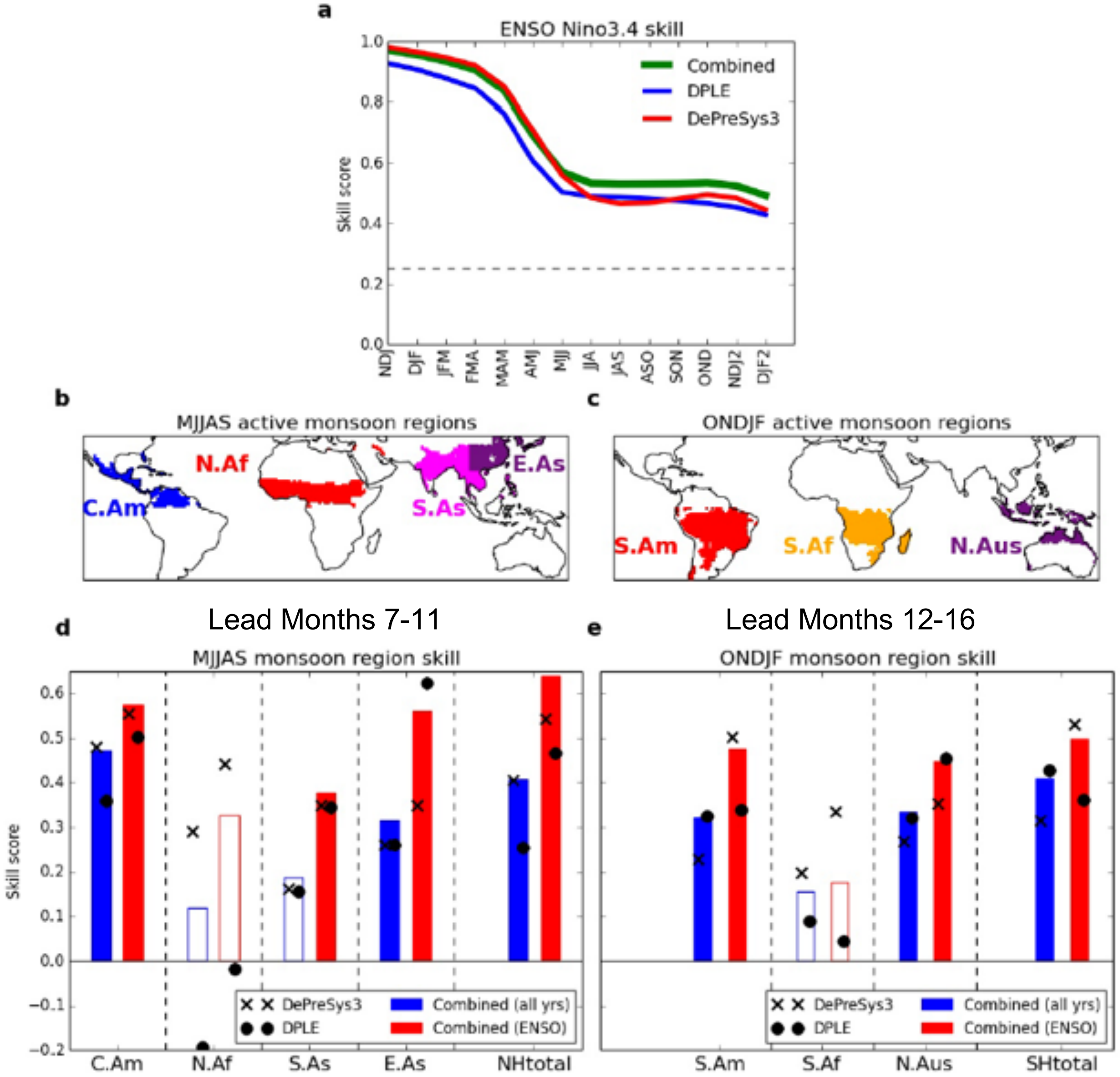


- High-degree of state-dependent predictability for UOHC in the North Atlantic quantified using relative entropy
- For some start years, information content *increases* with lead time
- Highlights the use of advanced statistical methods that take into account both mean and spread to elucidate potential predictability

Christensen et al. (2020)

Skillful Interannual Climate Prediction

- Combined analysis of DePreSys3 and DPLE (both 40-member systems) over lead months 1-16
- Active ENSO years enhance skill for monsoon rainfall
- Direct comparison with DePreSys3 indicates CESM-DPLE has comparable (but generally somewhat lower) skill.
- DPLE shows signs of initialization shock that impacts tropical African precipitation at early leads



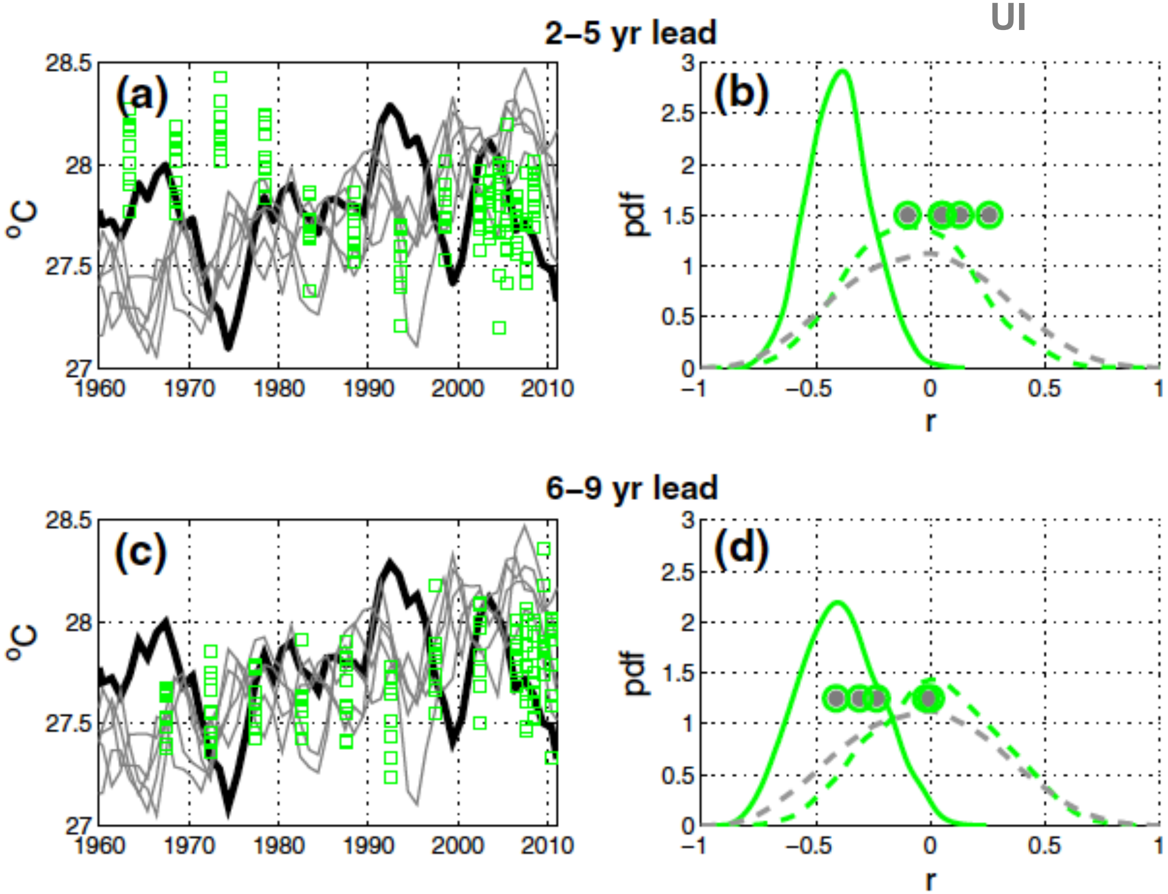
Dunstone et al. (2020)

A Key Outstanding Challenge: Initialization shock

CCSM4 (CMIP5)

Central Tropical Pacific Skill:

OBS
DP
UI

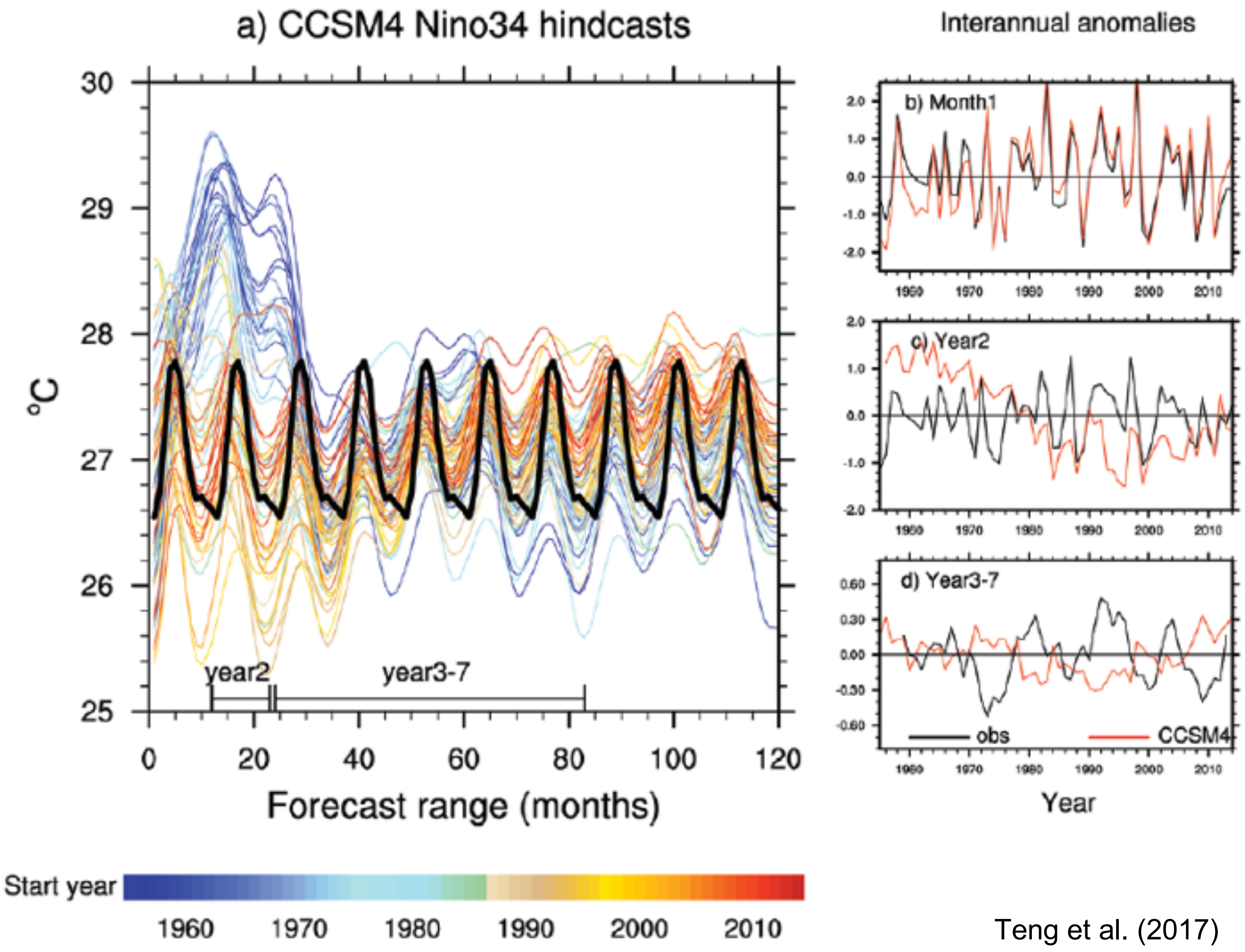


1961-2006 forecast starts

Karspeck et al. (2014)

A Key Outstanding Challenge: Initialization shock

CCSM4 (CMIP5)



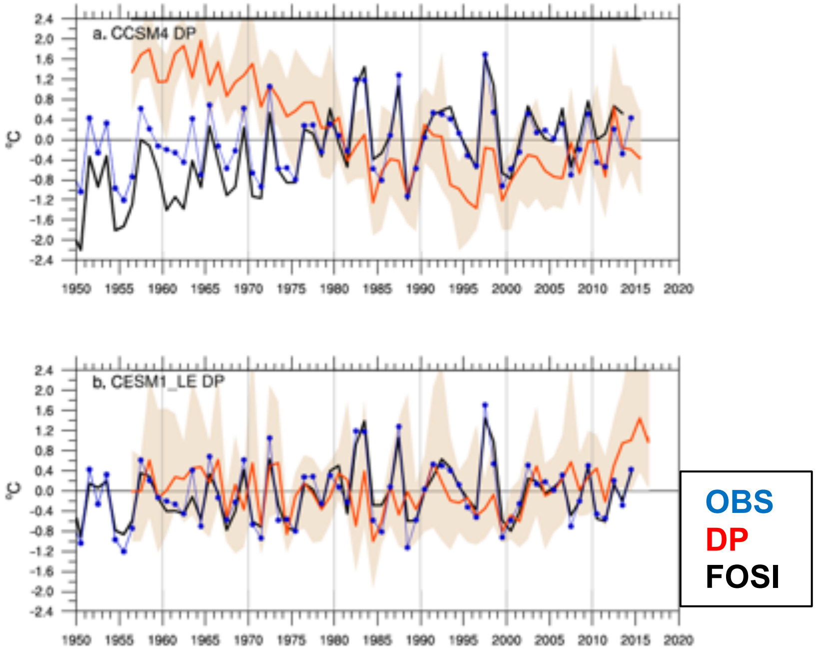
Teng et al. (2017)

A Key Outstanding Challenge: Initialization shock

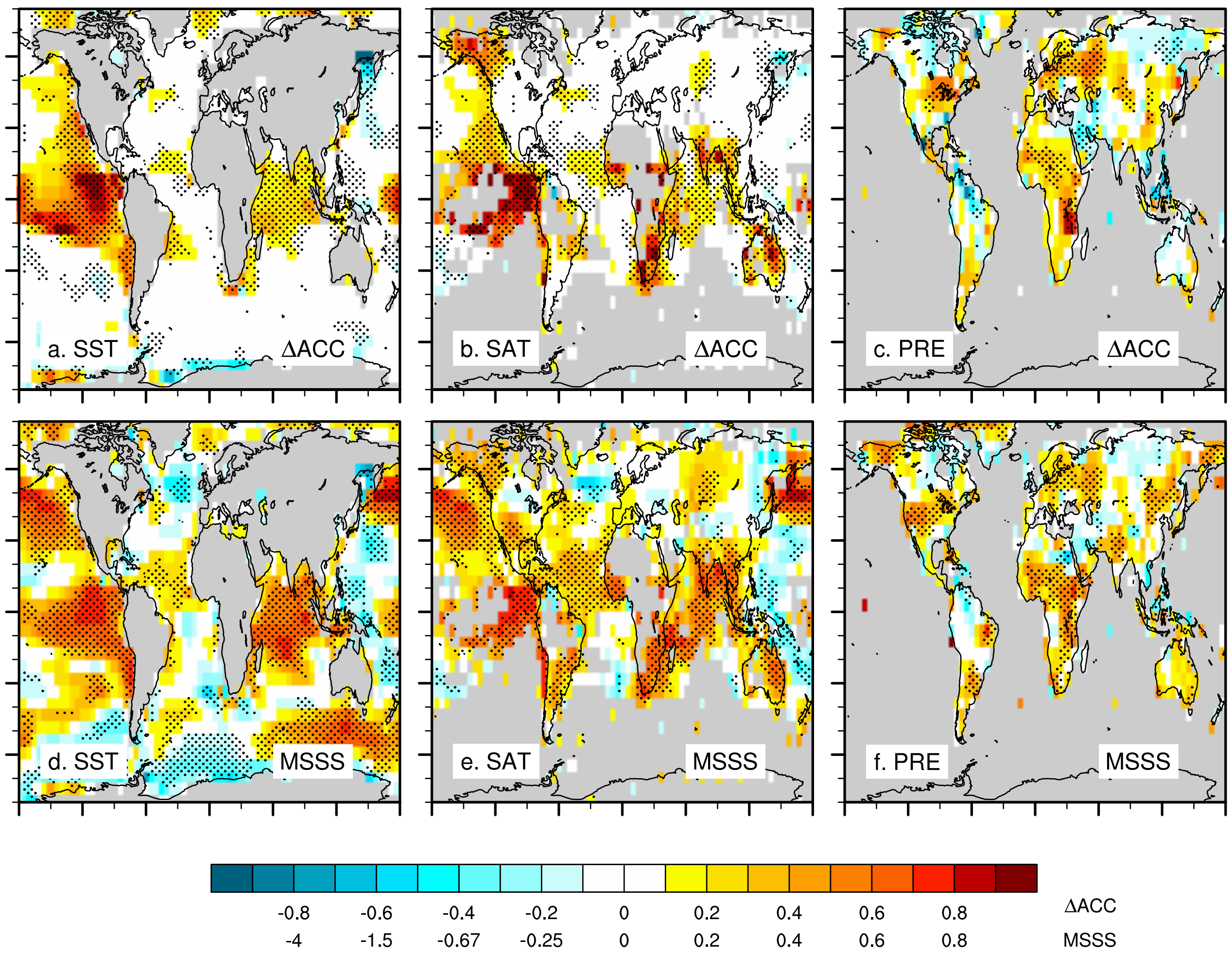
CESM-DPLE (CMIP6)

- Significant shock reduction achieved by correcting spurious trend in Eq. Pacific zonal wind stress used in FOSI simulation

Nino3, LY2:

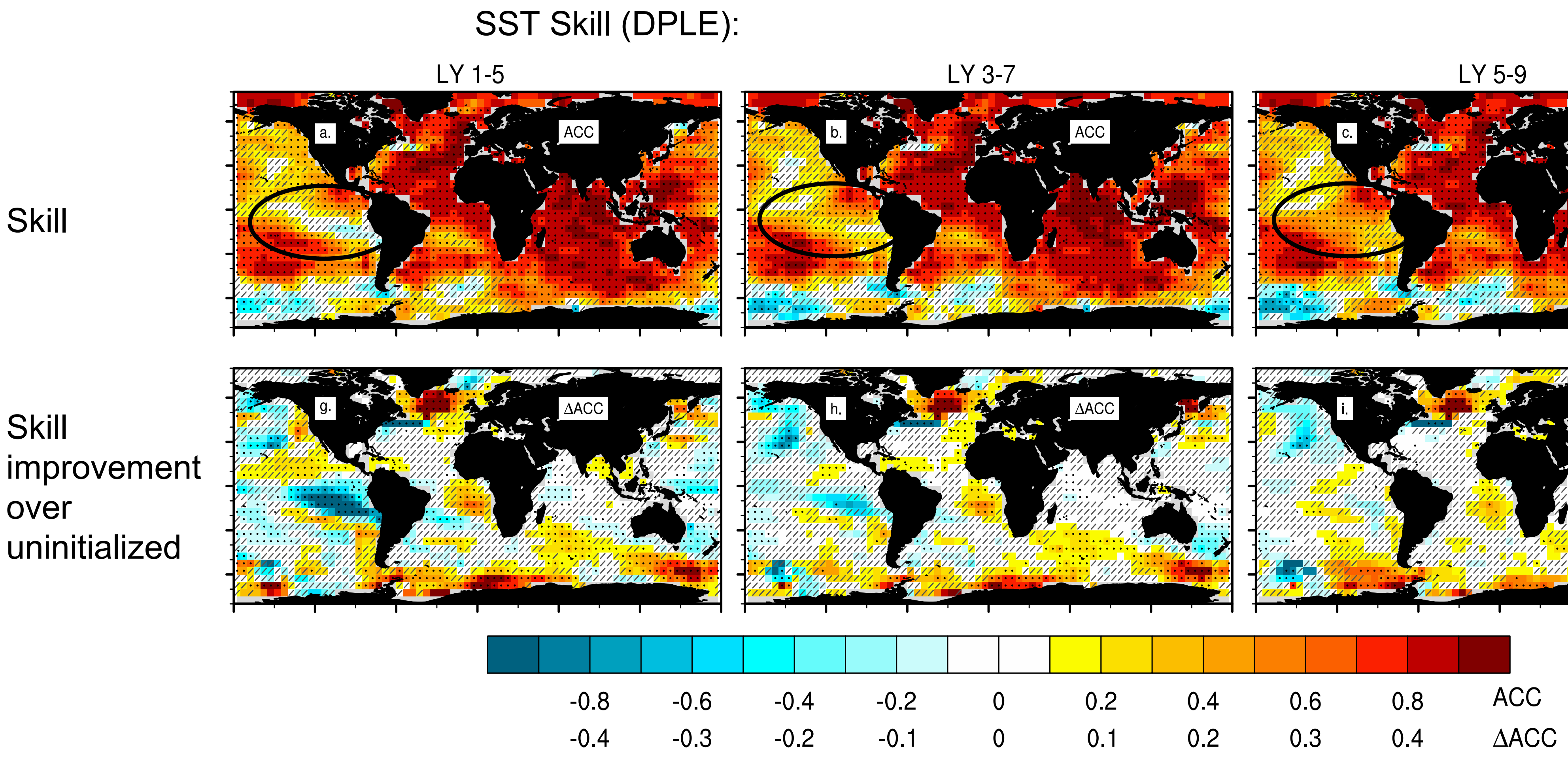


Skill difference (DPLE-CCSM4) for LY1-5:



Yeager et al. (2018)

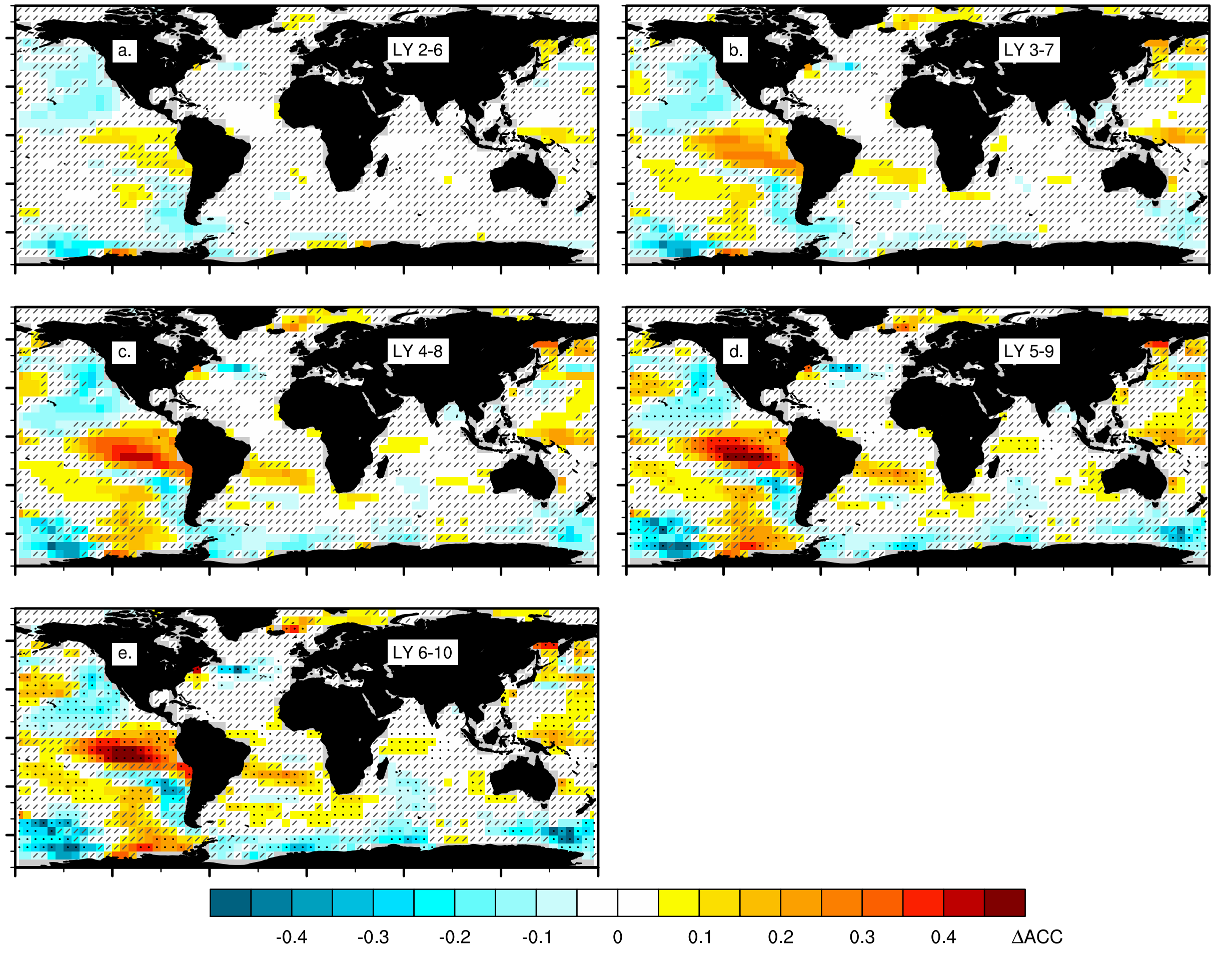
A Key Outstanding Challenge: Initialization shock



Yeager et al. (2018)

A Key Outstanding Challenge: Initialization shock

Skill difference from LY1-5:

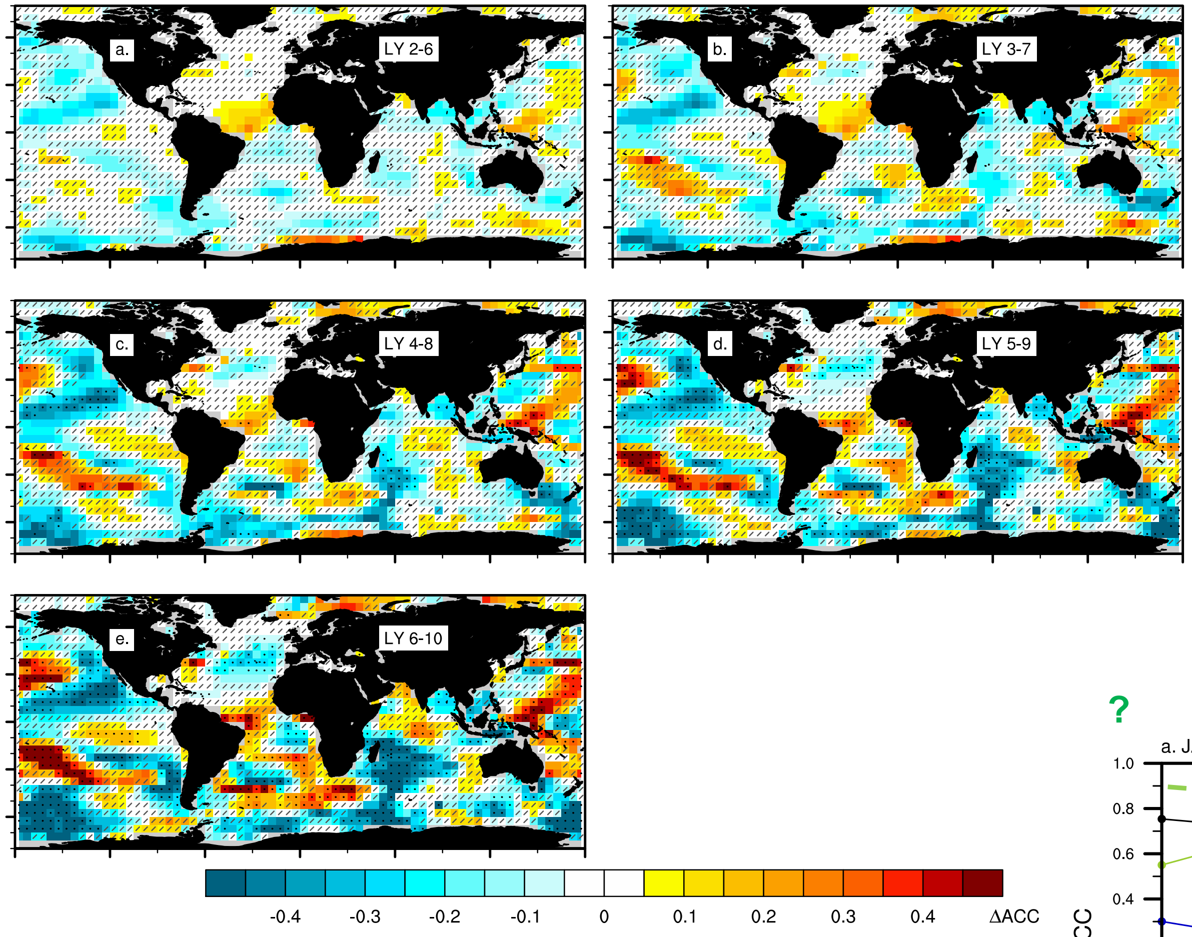


- SST skill (with trend included) shows improvement with lead time in tropical Pacific

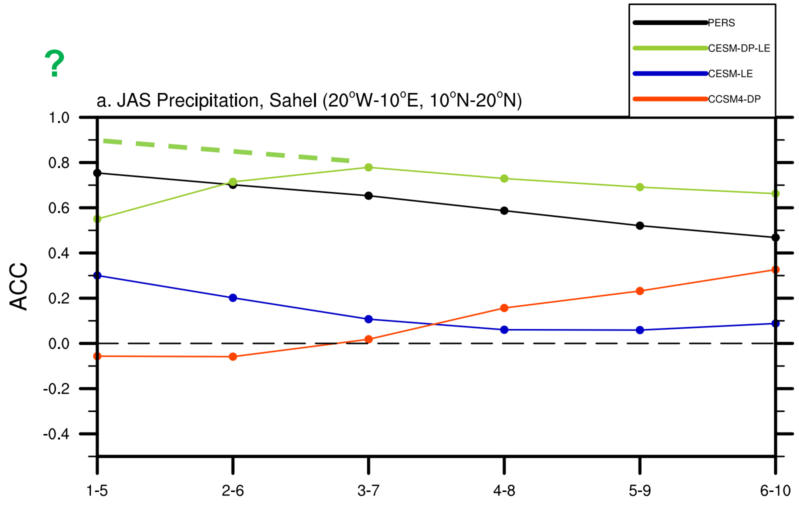
Yeager et al. (2018)

A Key Outstanding Challenge: Initialization shock

Skill difference from LY1-5:



- SST skill (with trend removed) highlights improvement with lead time in tropical Atlantic
- How can we improve initialization to minimize shock, & maximize skill at early lead times?



Yeager et al. (2018)

Closing Thoughts

- CESM-DPLE continues to exceed expectations and preliminary work suggests that it is a top-tier contribution to CMIP6-DCPP.
- Recent analyses have contributed greatly to our understanding of DPLE, but more scrutiny by the community is needed—please explore this dataset!
- Successful prediction (high skill) yields high-profile papers, but to advance we need a deeper understanding of prediction system behavior in general (good and bad) and efficient ways to test new methods. How do we share negative/disappointing results that expose prediction system failure?
- Key challenges for advancing CESM decadal prediction: initialization shock, model drift, atmospheric signal-to-noise, multi-component initialization, distributed-but-coordinated approach to system development/testing

Bibliography

- Athanasiadis, P., S. G. Yeager, Y.-O. Kwon, A. Bellucci, and S. Tibaldi, 2020: Decadal predictability of North Atlantic blocking and the NAO, *npj Clim Atmos Sci*, 3:20, doi:10.1038/s41612-020-0120-6.
- Brady, R. X., N. S. Lovenduski, S. G. Yeager, M. C. Long, K. Lindsay, 2020: Skillful multiyear predictions of ocean acidification in the California Current System, Nature Comm., 11:2166, DOI:10.1038/s41467-020-15722-x.
- Christensen, H. M., J. Berner, S. Yeager, 2020: The value of initialisation on decadal timescales: state dependent predictability in the CESM Decadal Prediction Large Ensemble, *J. Climate*, in press.
- Dunstone, N., D. Smith, S. Yeager, P.-A. Monerie, L. Hermanson, R. Eade, S. Ineson, J. Robson, A. Scaife, H. L. Ren, G. Danabasoglu, 2020: Assessing interannual climate prediction skill using two large initialised model ensembles, *Env. Res. Lett.*, in review.
- Karspeck, A., S. Yeager, G. Danabasoglu, H. Teng, 2014: An evaluation of experimental decadal predictions using CCSM4, *Clim Dyn*, DOI:10.1007/s00382-014-2212-7.
- Krumhardt, K. M., N. S. Lovenduski, M. C. Long, J. Y. Luo, K. Lindsay, S. Yeager, C. Harrison, 2020: Potential predictability of net primary production in the ocean, *Glob. Biogeochem. Cyc*., 34, e2020GB006531, DOI:10.1029/2020GB006531.
- Lovenduski, N. S., S. G. Yeager, K. Lindsay, M. C. Long, 2019a: Predicting near-term variability in ocean carbon uptake, *Earth Syst. Dynam.*, 10, 45-57, DOI:10.5194/esd-10-45-2019.
- Lovenduski, N. S., G. B. Bonan, S. G. Yeager, K. Lindsay, D. Lombardozzi, 2019b: High predictability of terrestrial carbon fluxes from an initialized decadal prediction system, *Environ. Res. Lett.,* 14, 124074, DOI:10.1088/1748-9326/ab5c55.
- Simpson, I. R., S. G. Yeager, K. A. McKinnon, C. Deser, 2019: Decadal predictability of late winter precipitation in western Europe through an ocean–jet stream connection, *Nat. Geosci*., 12, 613-619, doi: 10.1038/s41561-019-0391-x.
- Teng, H., G. A. Meehl, G. Branstator, S. Yeager, A. Karspeck, 2017: Initialization Shock in CCSM4 Decadal Prediction Experiments, *CLIVAR Exchanges*, DOI:10.22498/pages.25.1.41.
- Yeager, S. G., G. Danabasoglu, N. Rosenbloom, W. Strand, S. Bates, G. Meehl, A. Karspeck, K. Lindsay, M. C. Long, H. Teng, and N. S. Lovenduski, 2018: Predicting near-term changes in the Earth System: A large ensemble of initialized decadal prediction simulations using the Community Earth System Model, *Bull. Amer. Met. Soc.*, 99, 1867-1886, DOI:10.1175/BAMS-D-17-0098.1.
- Yeager, S. G., 2020: The abyssal origins of North Atlantic decadal predictability, *Clim. Dyn*., in review.