UFS S2S Application Team Webinar
March 15, 2024

The CESM2 Seasonal-to-Multiyear Large Ensemble (SMYLE) Forecast System: Past Performance and Recent Applications

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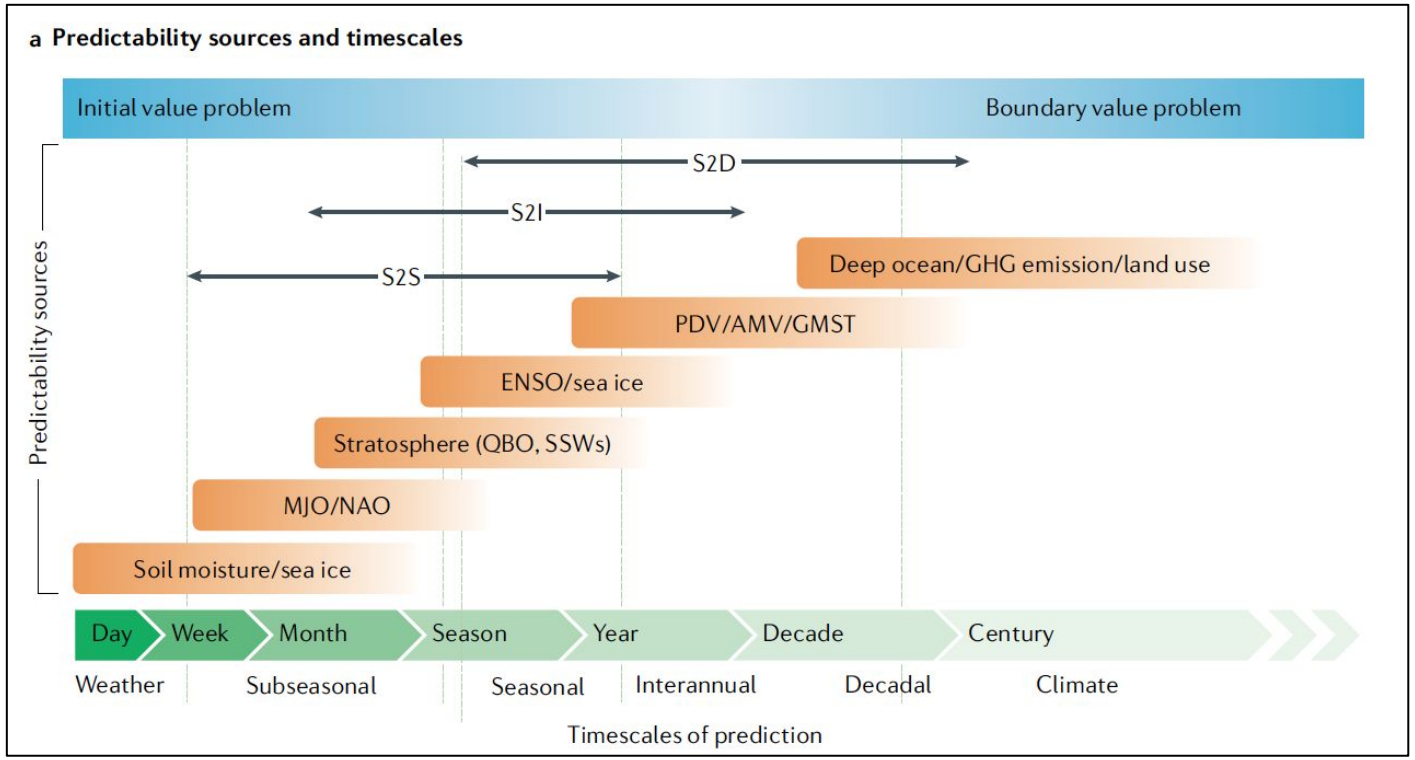
Initialized Earth System Prediction with CESM

- CESM's Earth System Prediction Working Group (ESPWG) was founded in 2020 to coordinate initialized prediction research across the CESM community

- Provide a community nexus for research into:

  - the fundamental origins, mechanisms, and limits of Earth system predictability
  - the fidelity of coupled model behavior
  - the potential to deliver reliable, actionable advanced warning of near-term regional environmental change

Initialized Prediction **Forced Projection**



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

Initialized Earth System Prediction with CESM

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

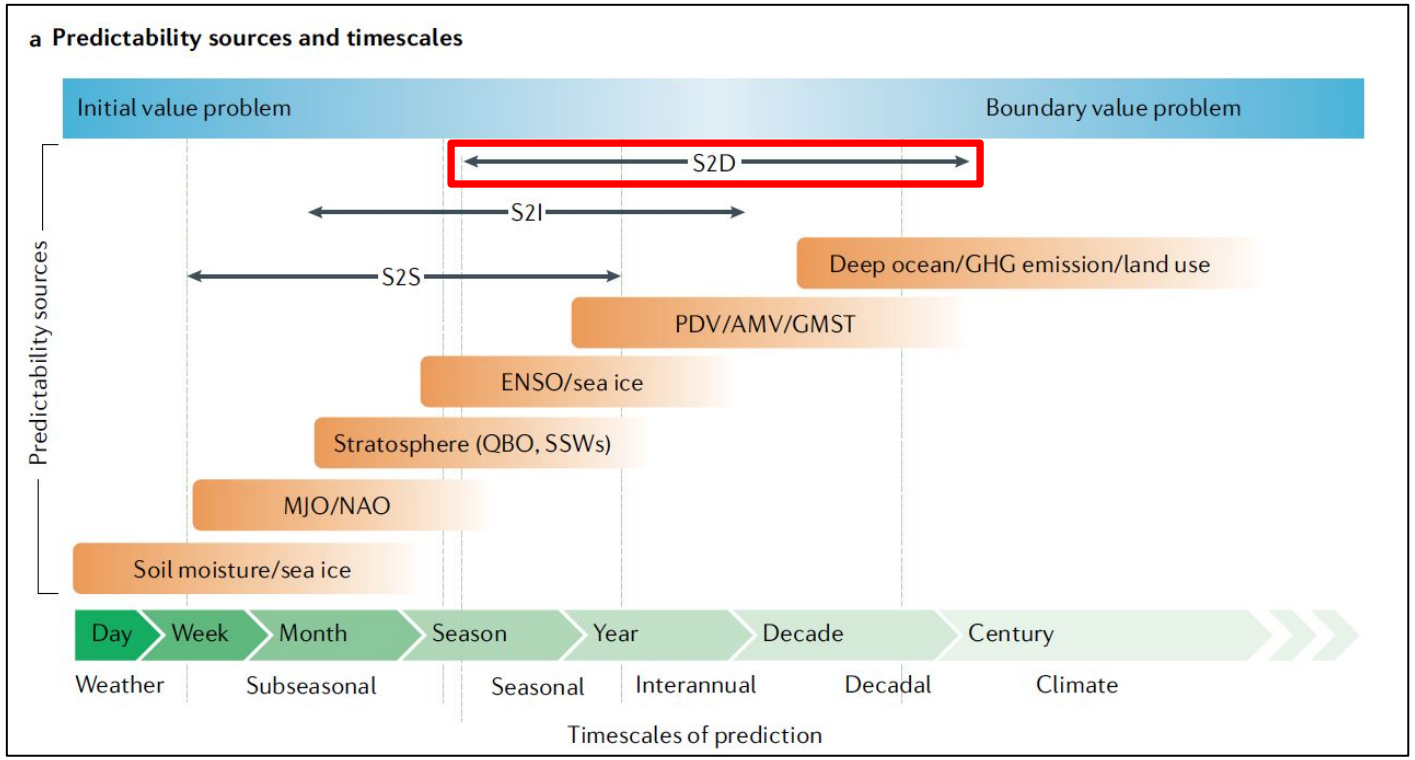
Yeager et al. (2018, *BAMS*, 10.1038/s41612-019-0071-y)

"CESM1-DPLE"

S2D system design:

- Annual initializations (Nov. 1st 1954-2020)
- 122-month simulations
- 40-member ensembles

 ~27,000 sim-years



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

Initialized Earth System Prediction with CESM

VOLUME 37 WEATHER AND FORECASTING JUNE 2022

Subseasonal Earth System Prediction with CESM2

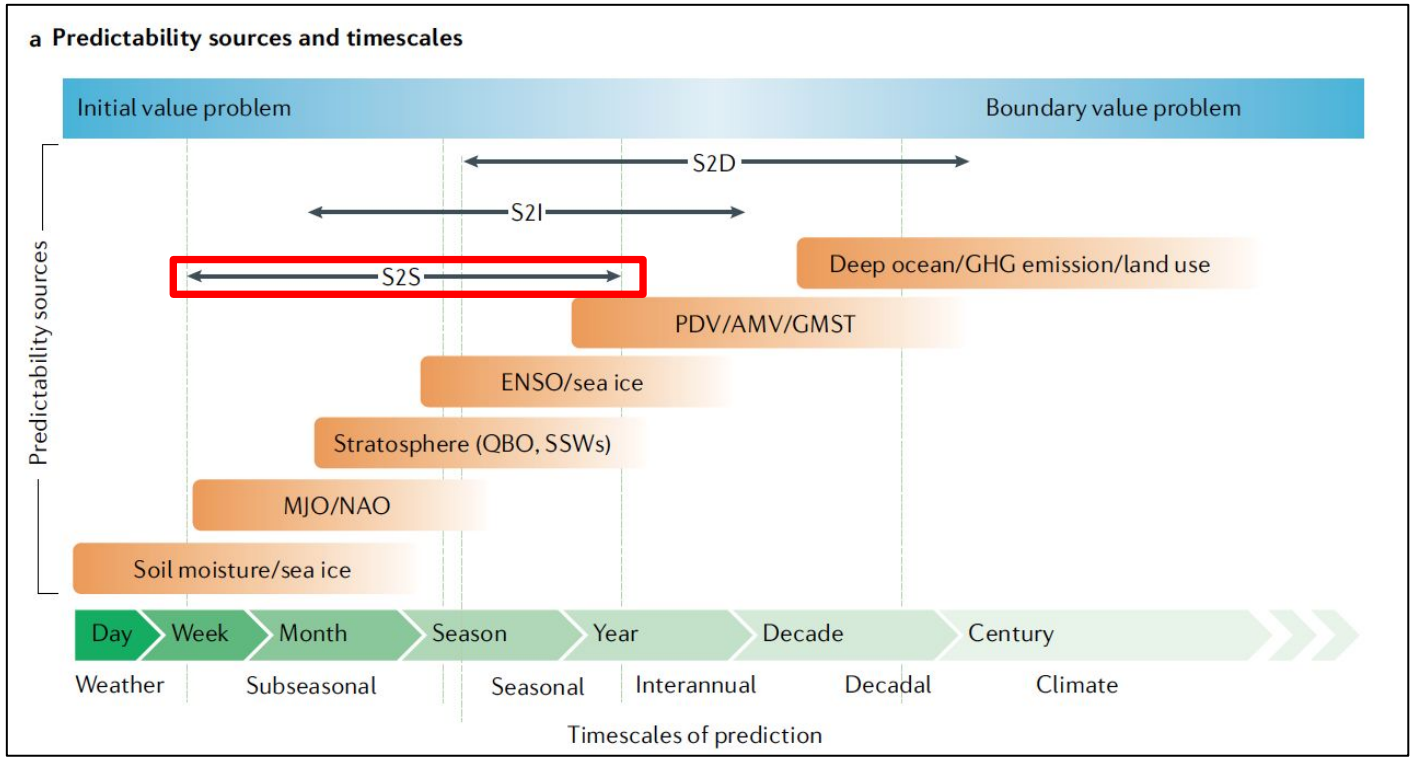
JADWIGA H. RICHTER,[a] ANNE A. GLANVILLE,[a] JAMES EDWARDS,[a] BRIAN KAUFFMAN,[a] NICHOLAS A. DAVIS,[b] ABIGAIL JAYE,[c] HYEMI KIM,[d] NICHOLAS M. PEDATELLA,[e] LANTAO SUN,[f] JUDITH BERNER,[c,a] WHO M. KIM,[a] STEPHEN G. YEAGER,[a] GOKHAN DANABASOGLU,[a] JULIE M. CARON,[a] AND KEITH W. OLESON[a]

Richter et al. (2022, *Wea. Forecasting*, 10.1175/WAF-D-21-0163.1)

S2S system design:

- Weekly initializations (1999-2020)
- 45-day simulations
- 11-member ensembles

 ~1,600 sim-years



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

Initialized Earth System Prediction with CESM

Geosci. Model Dev., 15, 6451–6493, 2022
https://doi.org/10.5194/gmd-15-6451-2022

Geoscientific Model Development
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EGU

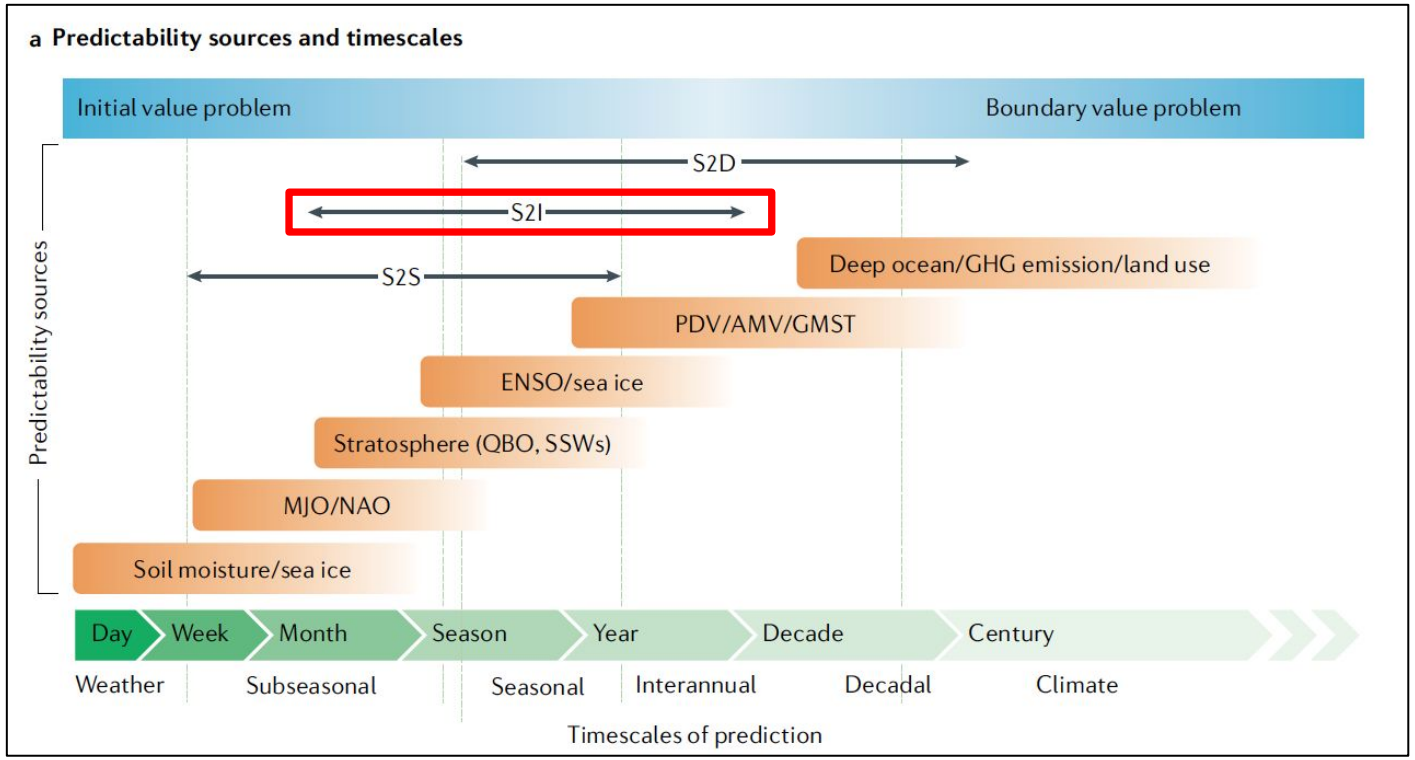
The Seasonal-to-Multiyear Large Ensemble (SMYLE) prediction system using the Community Earth System Model version 2

Stephen G. 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 M. Kim[1], Jadwiga H. Richter[1], Matthew Long[1], Gokhan Danabasoglu[1], David Bailey[1], Marika Holland[1], Nicole Lovenduski[2], Warren G. Strand[1], and Teagan King[1]

"CESM2-SMYLE"

S2I system design:
- Quarterly initializations (1st of Nov/Feb/May/Aug 1958-2020)
- 24-month simulations
- 20-member ensembles

□ ~10,000 sim-years



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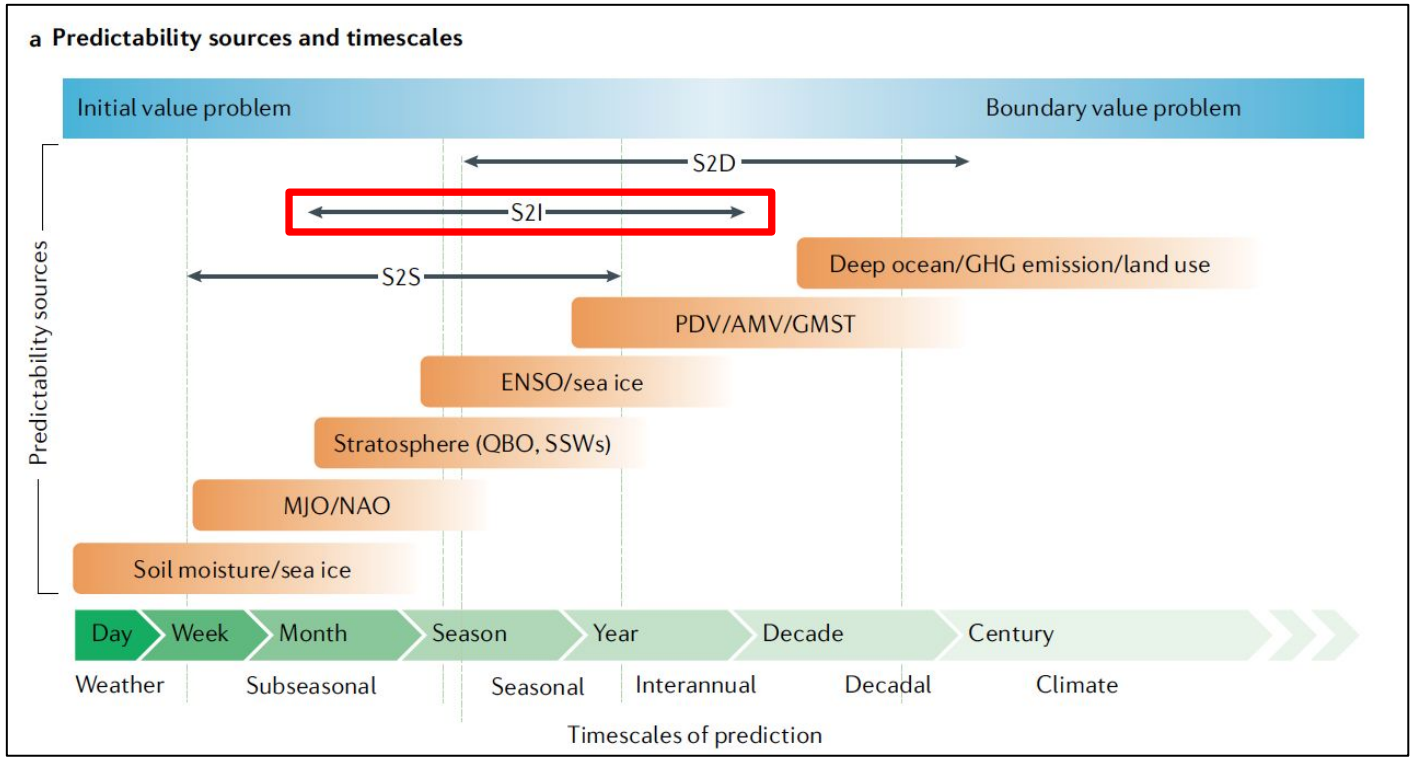
- ~1° CESM2 (CAM6-32L, POP2-60L, CICE5, CLM5)
- Prognostic ocean BGC (using MARBL)
- Ocean/Ice/BGC initialization:
  - -OMIP2 **F**orced **O**cean/**S**ea-**I**ce (FOSI) run
  - -JRA55-do forcing (Tsujino et al. 2018)
- Atmosphere initialization:
  - - JRA55 Reanalysis
- Land initialization:
  - - Forced land-only run
  - - CRU-JRAv2 forcing (TRENDY S3 protocol; Friedlingstein et al. 2020)



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

Ocean & Sea-ice Initialization

- Why initialize from FOSI-SMYLE?

  - “poor man’s data assimiliation” for ocean/ice/BGC

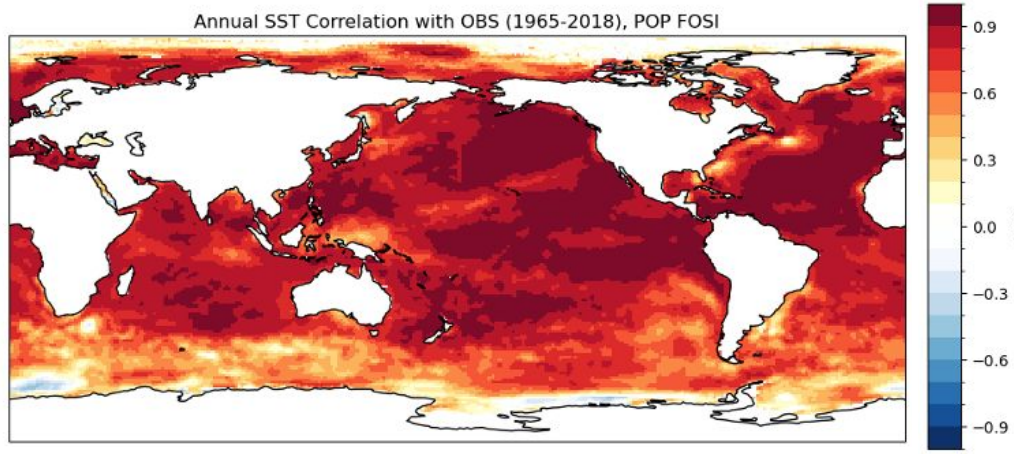
  - yields consistent observation-based estimates of historical ocean/sea-ice/ocean-BGC states

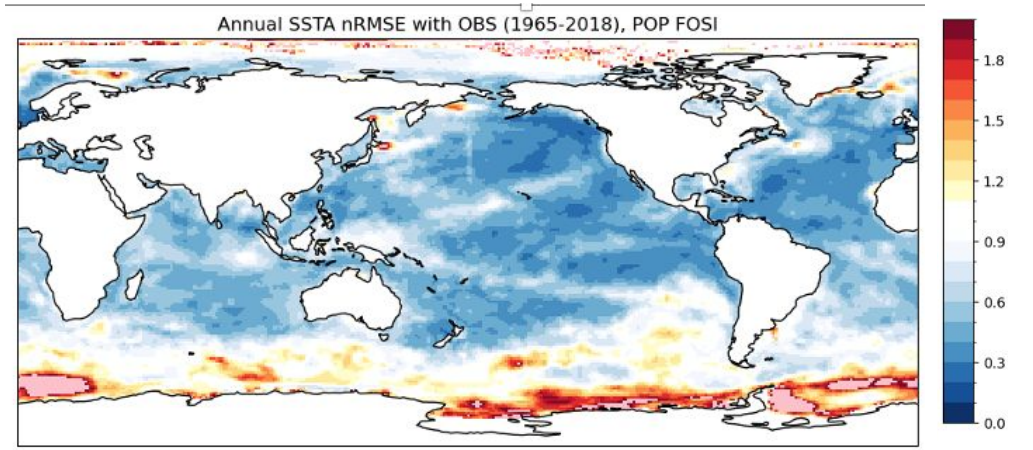
  - builds off work of CLIVAR’s Ocean Model Development Panel & NCAR’s Oceanography group

  - good reproduction of key observed variability (e.g. ENSO) extending back to 1958 (and forward to near real-time)

  - cheap, fast, and nimble (intended for community research, not operations)

- 5-cycle spin-up using OMIP2 forcing (1958-2018), with 6th cycle used for SMYLE

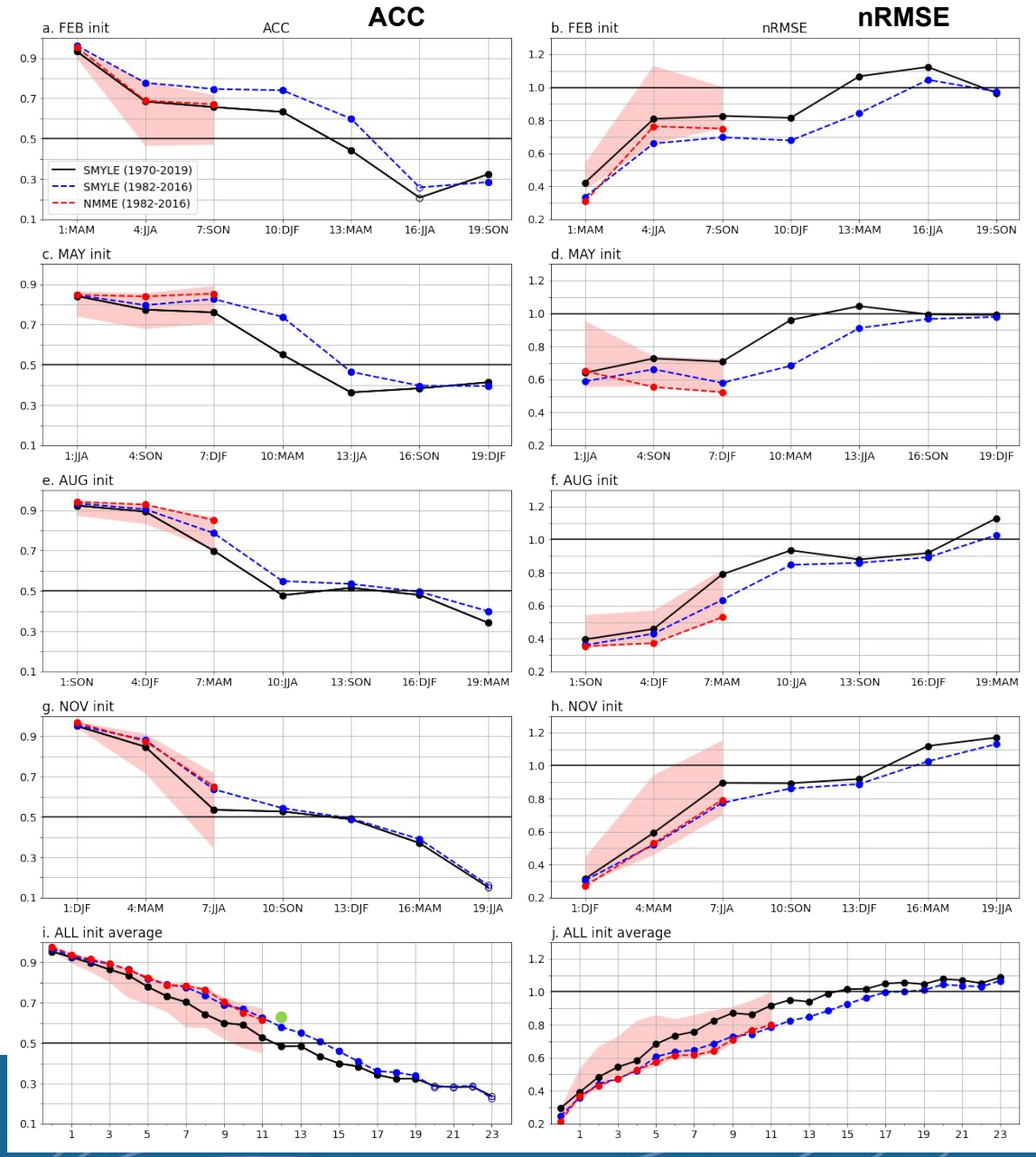




Skill: Niño-3.4 SST

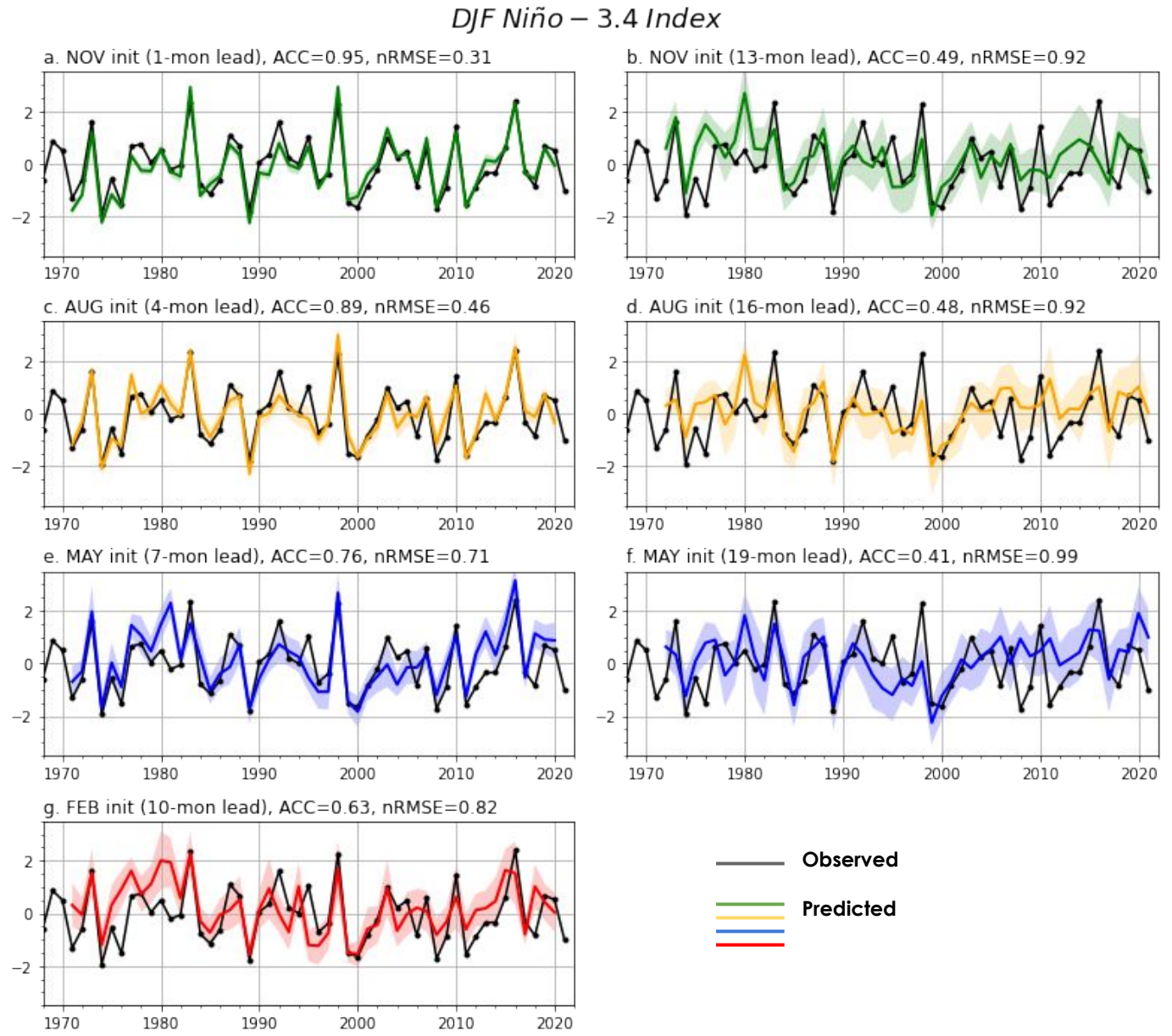
- SMYLE skill for **1982-2016** is higher than for **1970-2019**
- **SMYLE** skill compares well with 8-model **NMME** skill (significantly better for FEB-init)
- **SMYLE** skill for monthly Niño-3.4 only slightly lower than ECMWF **SEAS5** at 12-month lead

 SMYLE is a competitive seasonal/ENSO prediction system with several distinct advantages (multiyear leads, long verification window, full Earth system fields)



Skill: Niño-3.4 SST

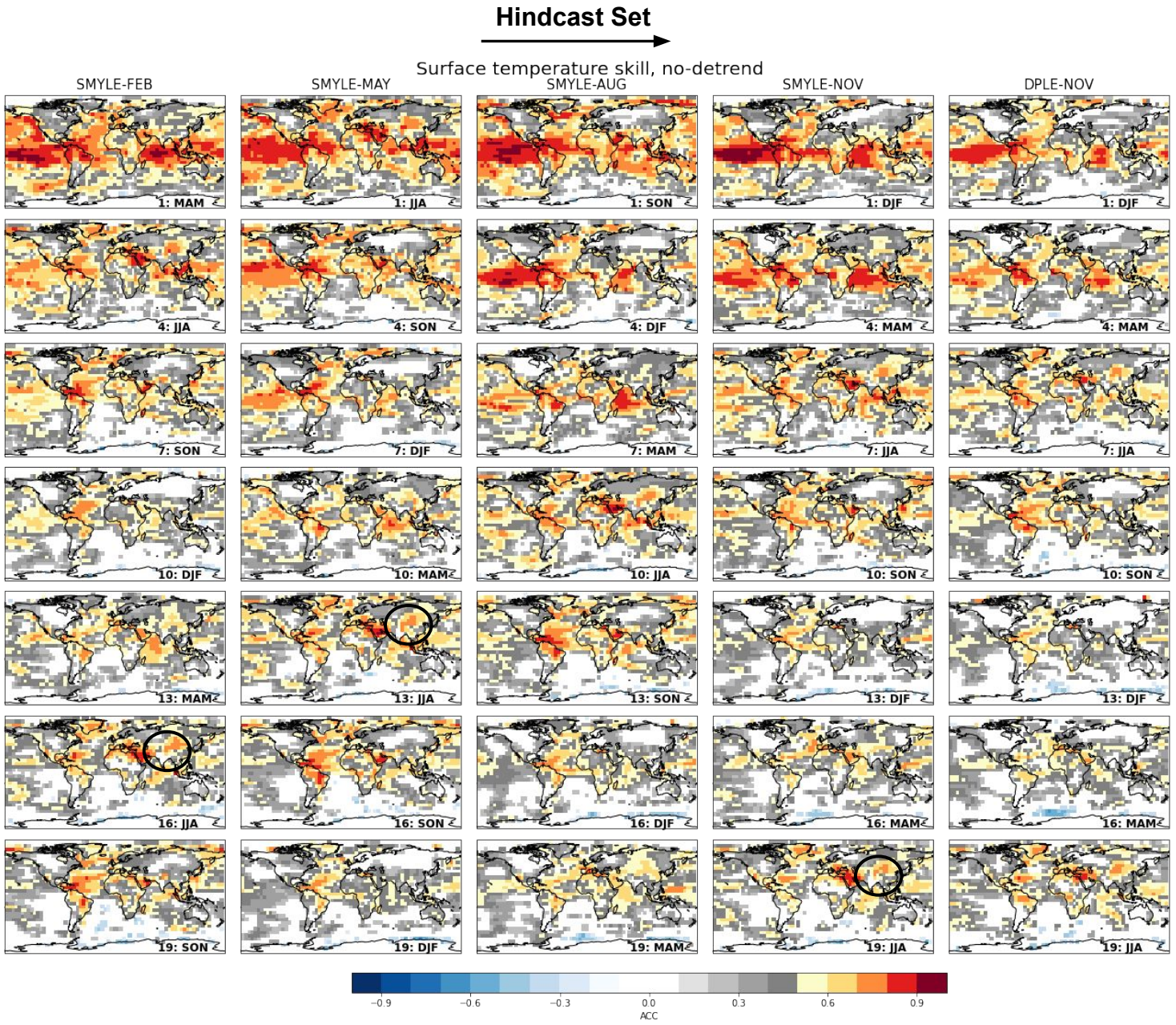
- Skill decrease with lead time
- **panel g**: potentially useful DJF Niño-3.4 forecasts at 10-month lead (ACC>0.6)
- **panel g**: spring predictability barrier can be overcome for strong events (1973, 1983, 1998, 2016 El Niños; 1974, 1989,1999, 2000 La Niñas)
- **panel f**: evidence of non-stationarity in Niño-3.4 skill—long lead skill and low spread in 1980s



Skill: Surface Temperature

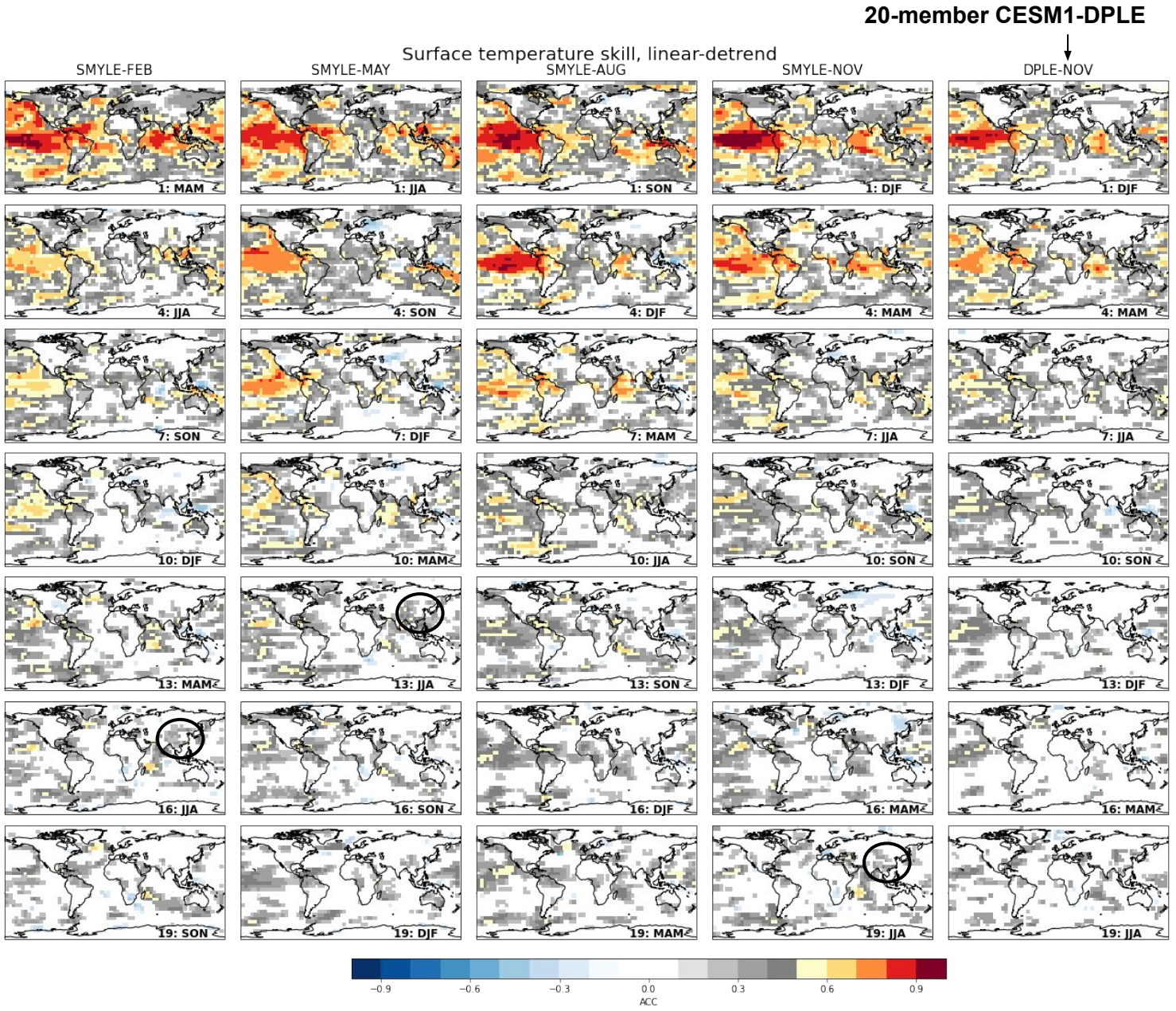
- Seasonal surface temperature ACC
- Verification data (1970-2020):
  - CRU-TS4.05 (land)
  - HadISST (ocean)
- Significant & potentially useful (ACC>0.5) skill out through 19-month leads (e.g. east Asia)

Lead Month: Target Season



Skill: Surface Temperature (detrended)

- Suggestion that initialization improves extended seasonal outlook
- Also, evidence of skill improvement in SMYLE compared to DPLE attributable to a combination of:
  - model physics (CESM2 vs. CESM1)
  - initialization methodology

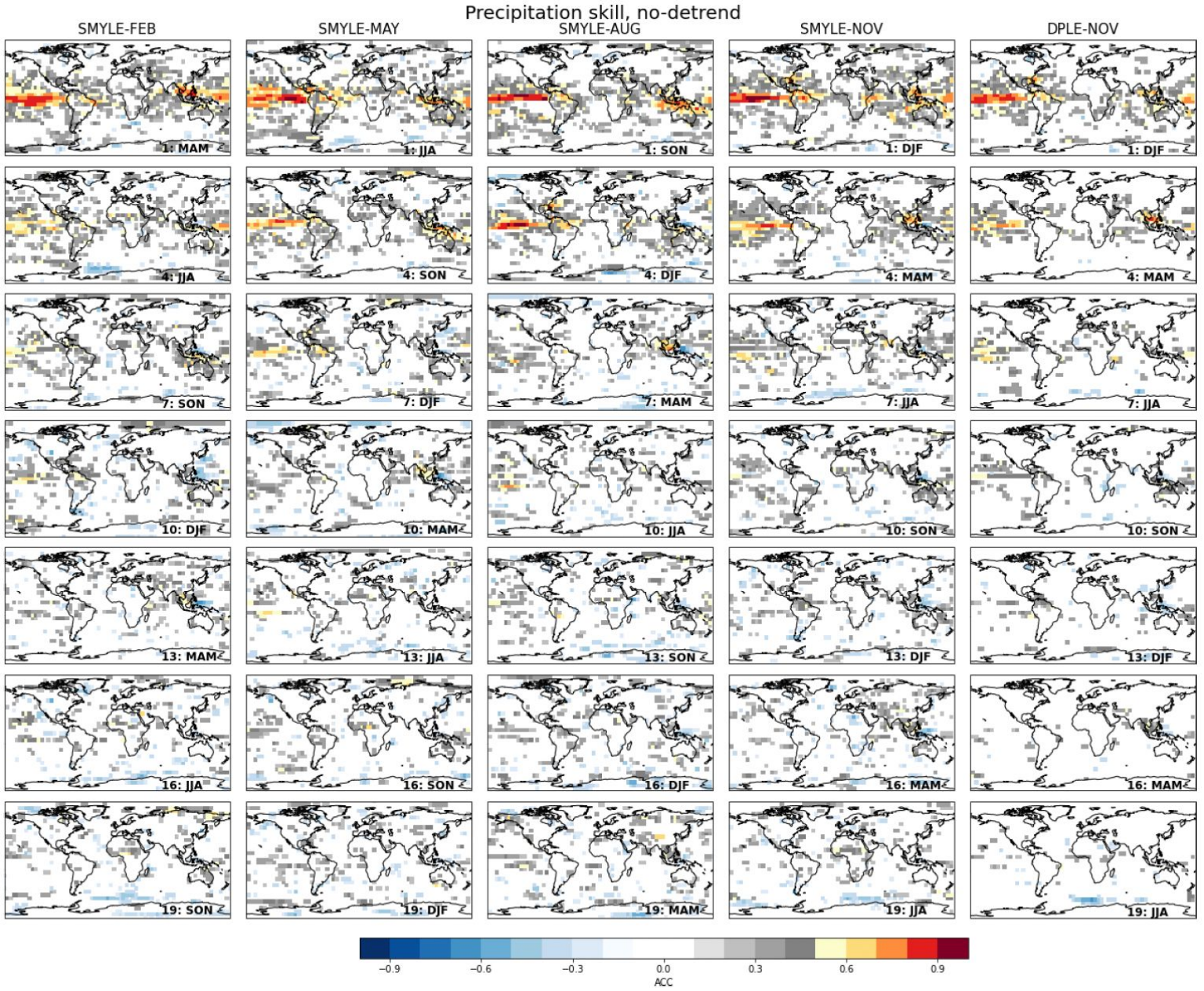


Skill: Precipitation

- Seasonal precipitation ACC
- Verification data (1979-2021):
  - GPCP v2.3

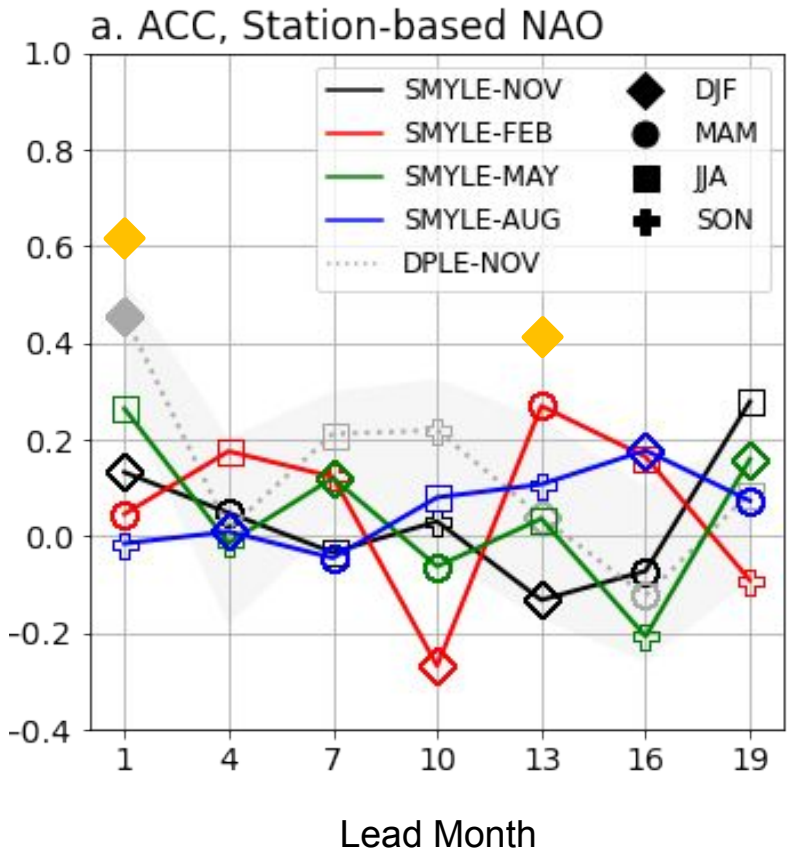
⇒ low skill for precipitation even at short leads

ACC:



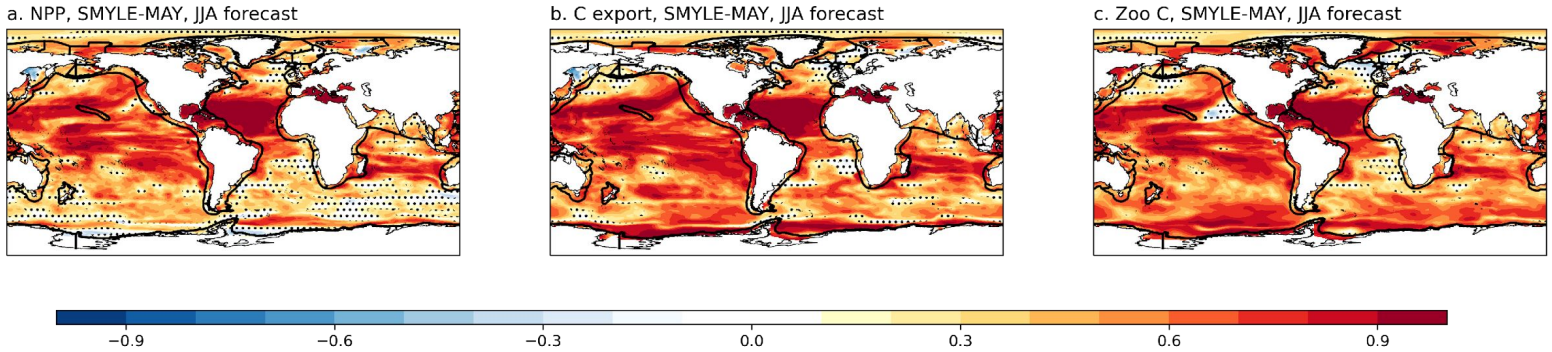
Skill: NAO

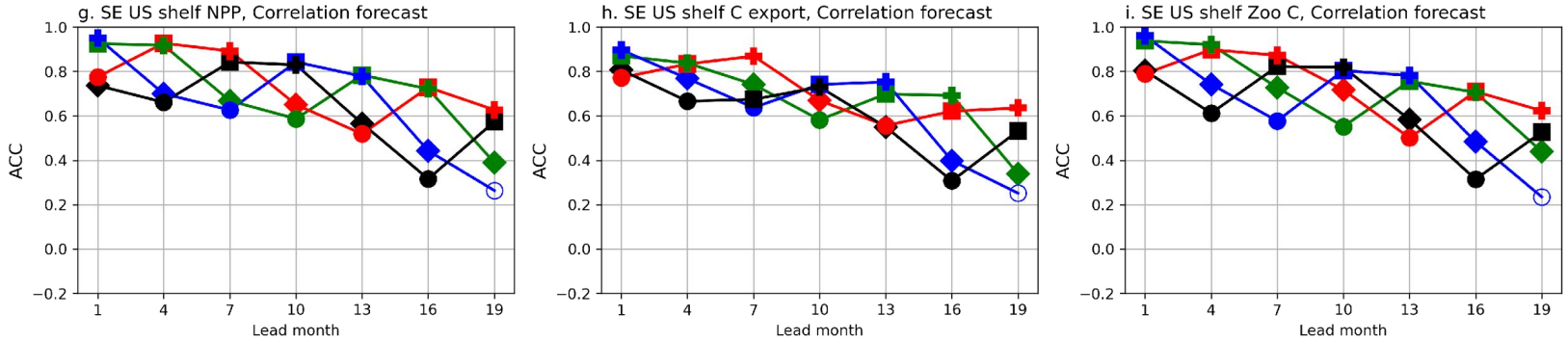
- Seasonal NAO ACC
- Verification data (1981-2015):
  - ERA5 Reanalysis
- Low skill that compares poorly to **UKMO** prediction system (Dunstone et al. 2016)



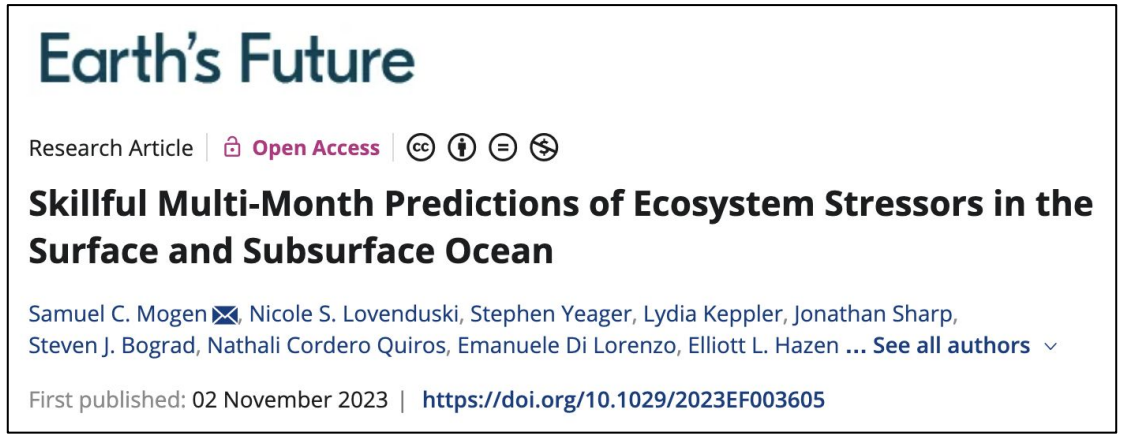
Potential Skill: Ocean Biogeochemistry

- Seasonal NPP/C-Export/Zoo-C ACC
- Verification data (1970-2019):
  - SMYLE-FOSI
- Encouraging potential for global S2I forecasts of marine BGC fields, with applications to fisheries in coastal large marine ecosystem (LME) regions

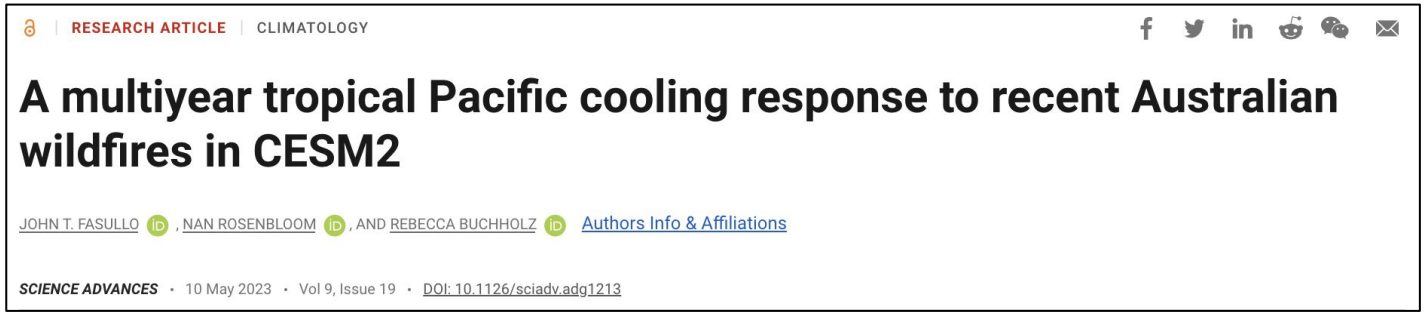




II. Recent Applications



- Growing number of published studies that utilize CESM2-SMYLE

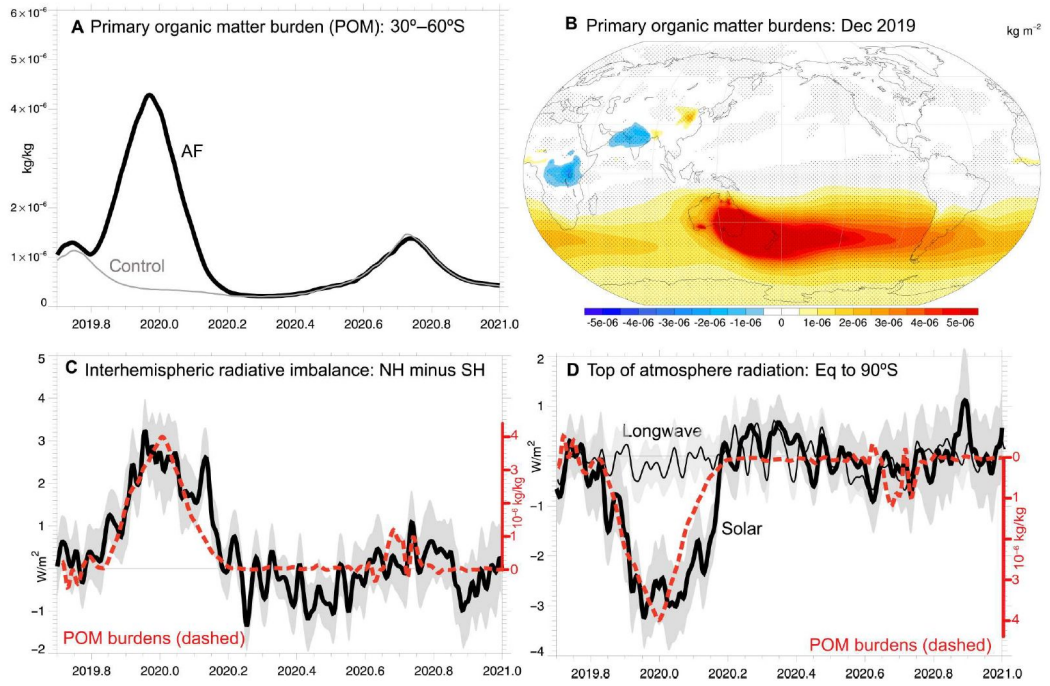


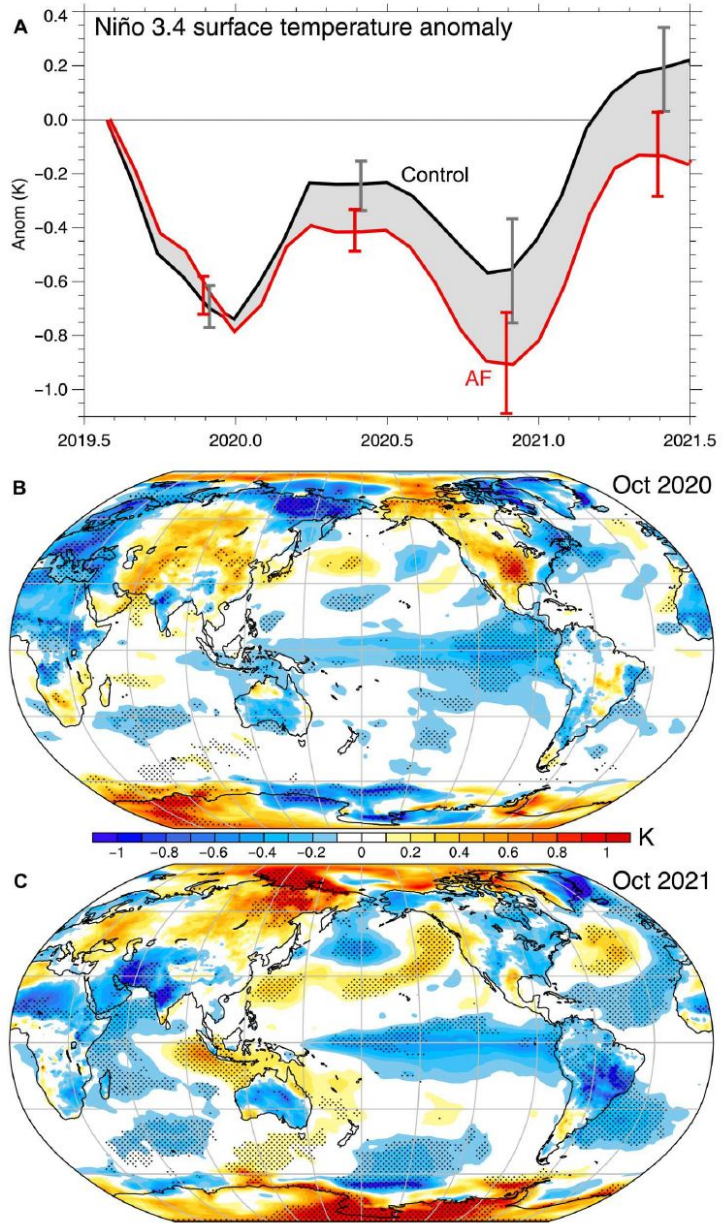
RESEARCH ARTICLE | CLIMATOLOGY

A multiyear tropical Pacific cooling response to recent Australian wildfires in CESM2

JOHN T. FASULLO, NAN ROSENBLOOM, AND REBECCA BUCHHOLZ Authors Info & Affiliations

SCIENCE ADVANCES • 10 May 2023 • Vol 9, Issue 19 • DOI: 10.1126/sciadv.adg1213





- Initialized attribution: SMYLE with/without Australian wildfire emissions suggests a role in recent multiyear La Niña

Earth's Future

Research Article | Open Access

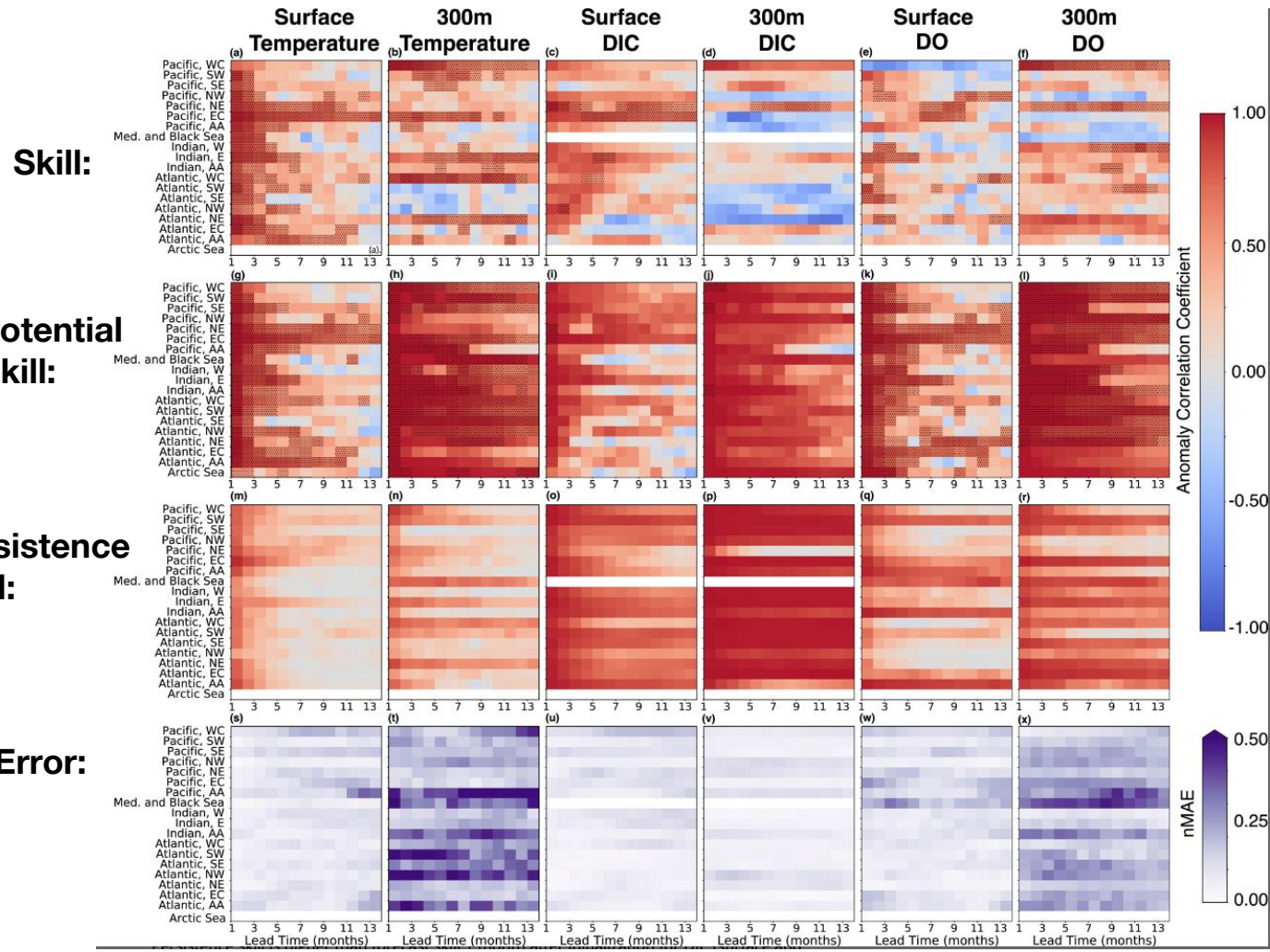
Skillful Multi-Month Predictions of Ecosystem Stressors in the Surface and Subsurface Ocean

Samuel C. Mogen, Nicole S. Lovenduski, Stephen Yeager, Lydia Keppler, Jonathan Sharp, Steven J. Bograd, Nathali Cordero Quiros, Emanuele Di Lorenzo, Elliott L. Hazen ... See all authors

First published: 02 November 2023 | https://doi.org/10.1029/2023EF003605

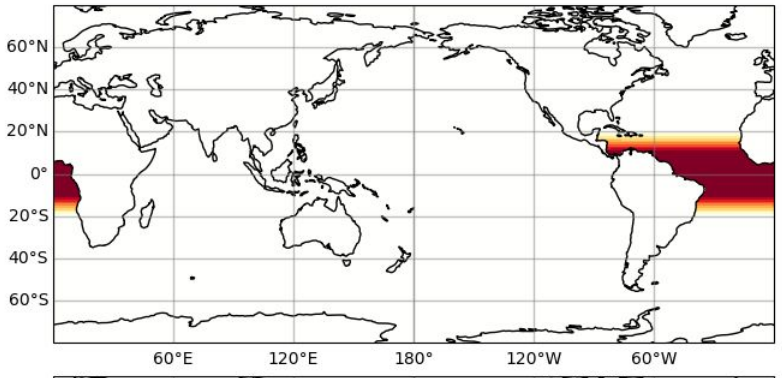
- Promising potential to predict marine ecosystem stressors up to a year in advance

Marine Ecosystem Stressors

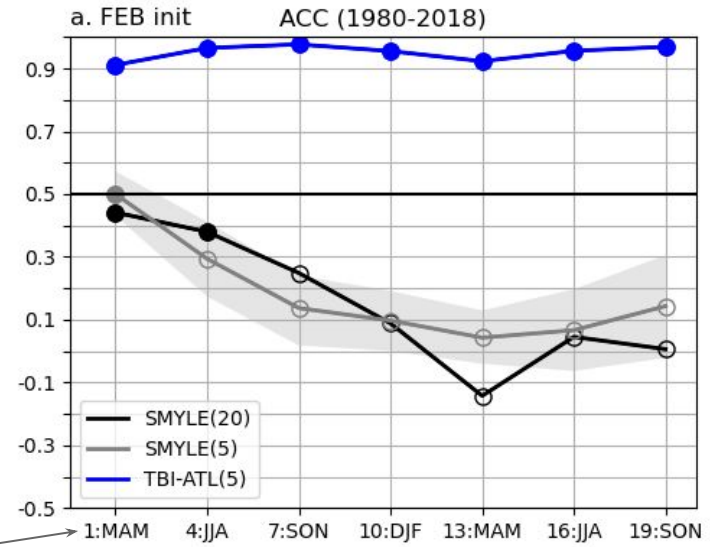


Exploring Predictability Mechanisms

- Prediction pacemaker experiments coordinated by CLIVAR's Tropical Basin Interaction panel.
- TBI-Atlantic: equivalent to SMYLE-FEB **except** SST anomalies are restored to observations in the tropical Atlantic (10°S-10°N).

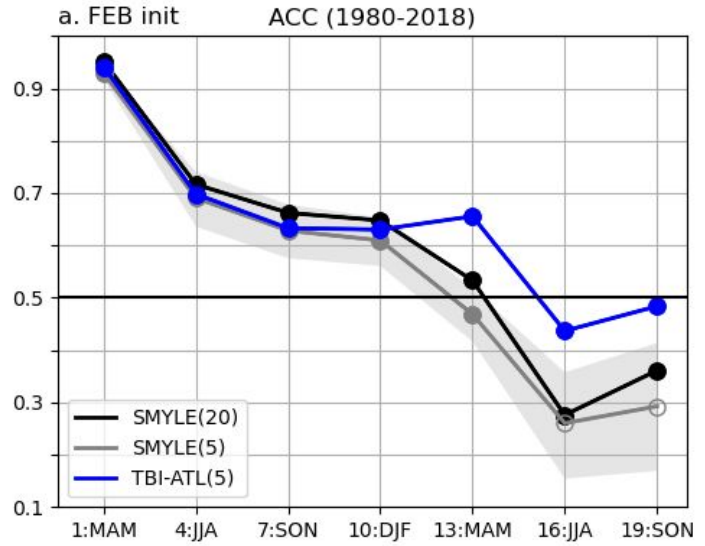


Atlantic Niño (ATL3)

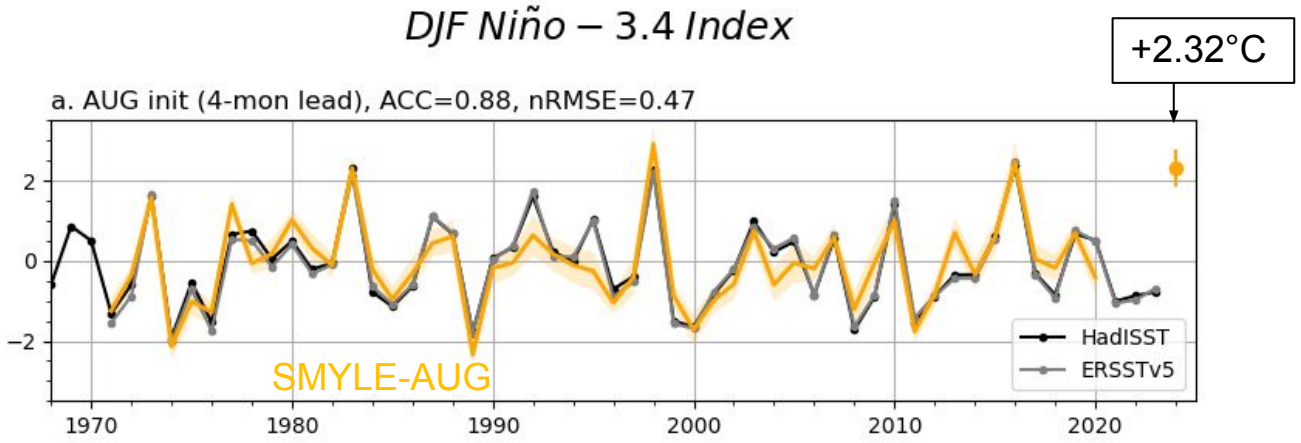


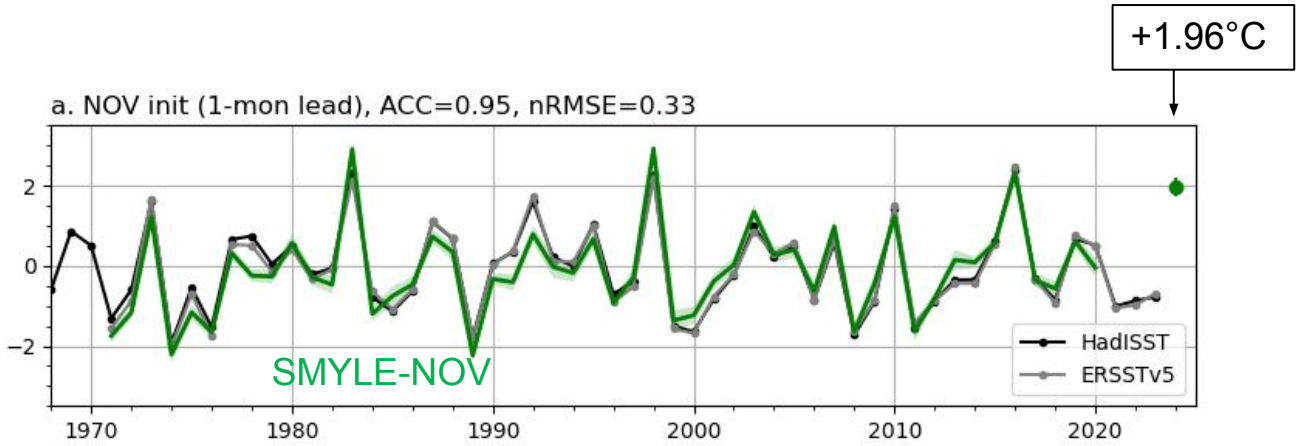
Lead month: Target season

Niño-3.4



Real-time Forecasts: El Niño 23/24

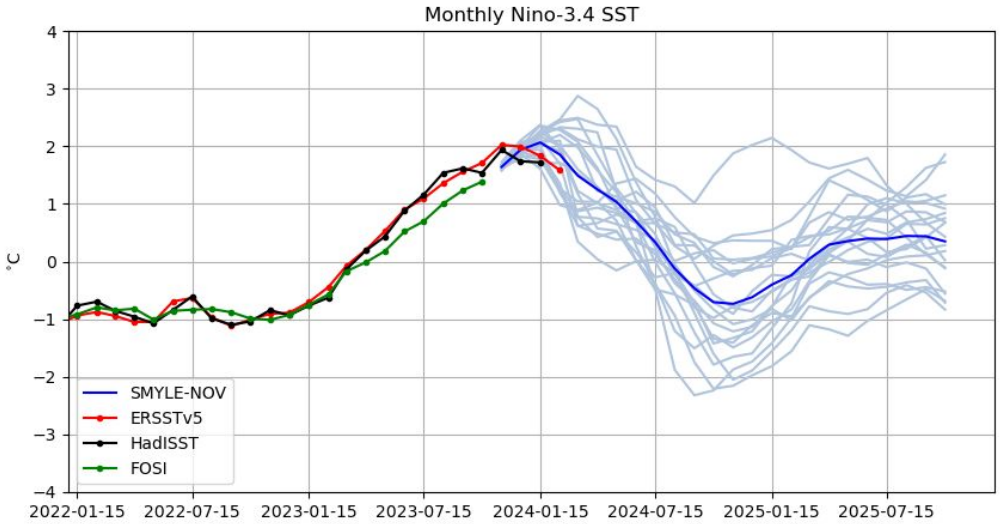


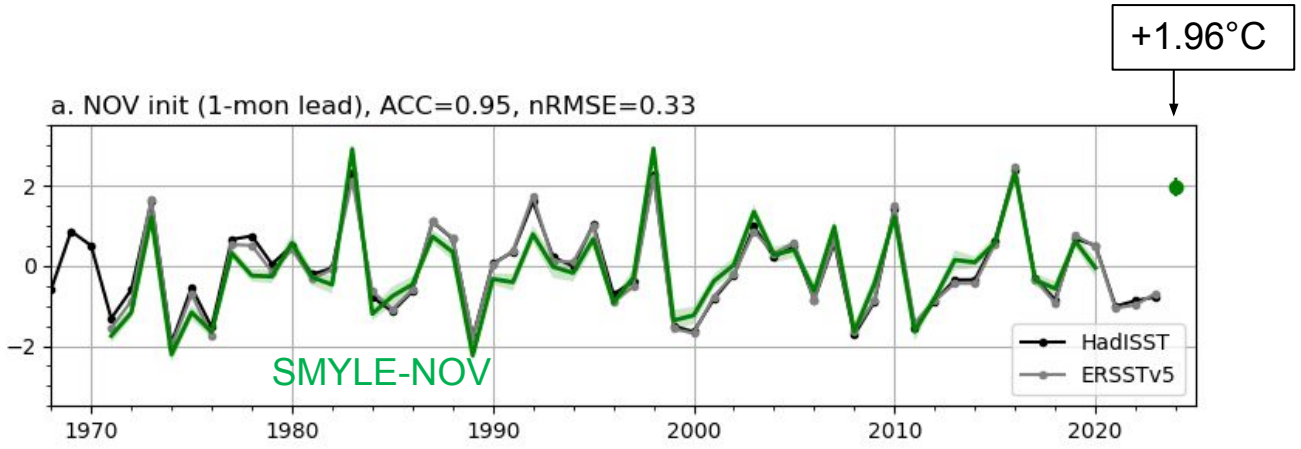


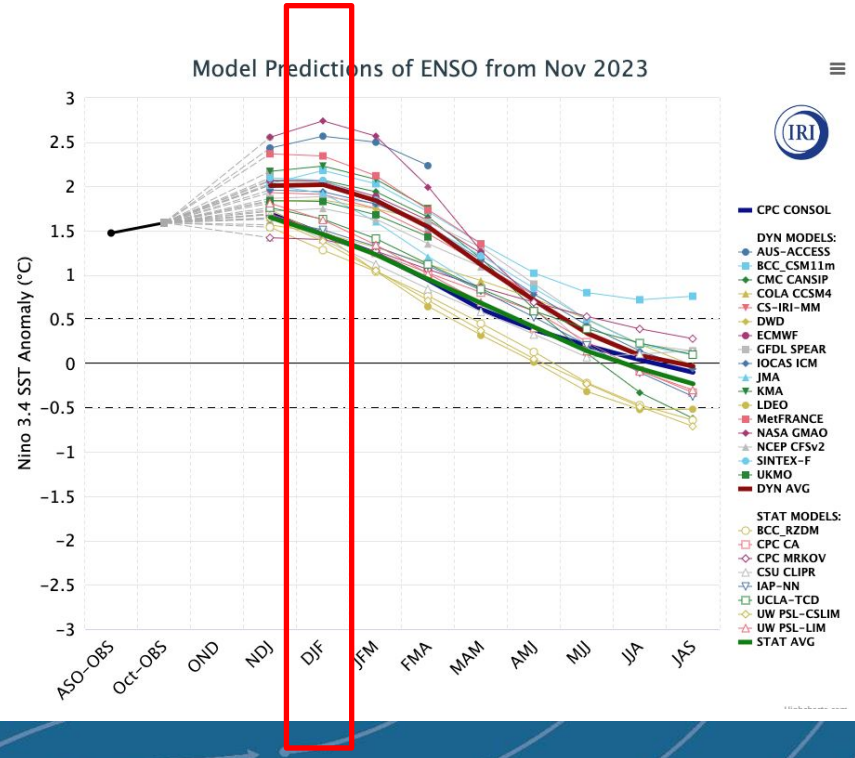
Real-time Forecasts: El Niño 23/24

- ERSSTv5 DJF Niño3.4 anomaly: +1.8°C

- **Real-time forecast capability opens up new science opportunities for CESM community**

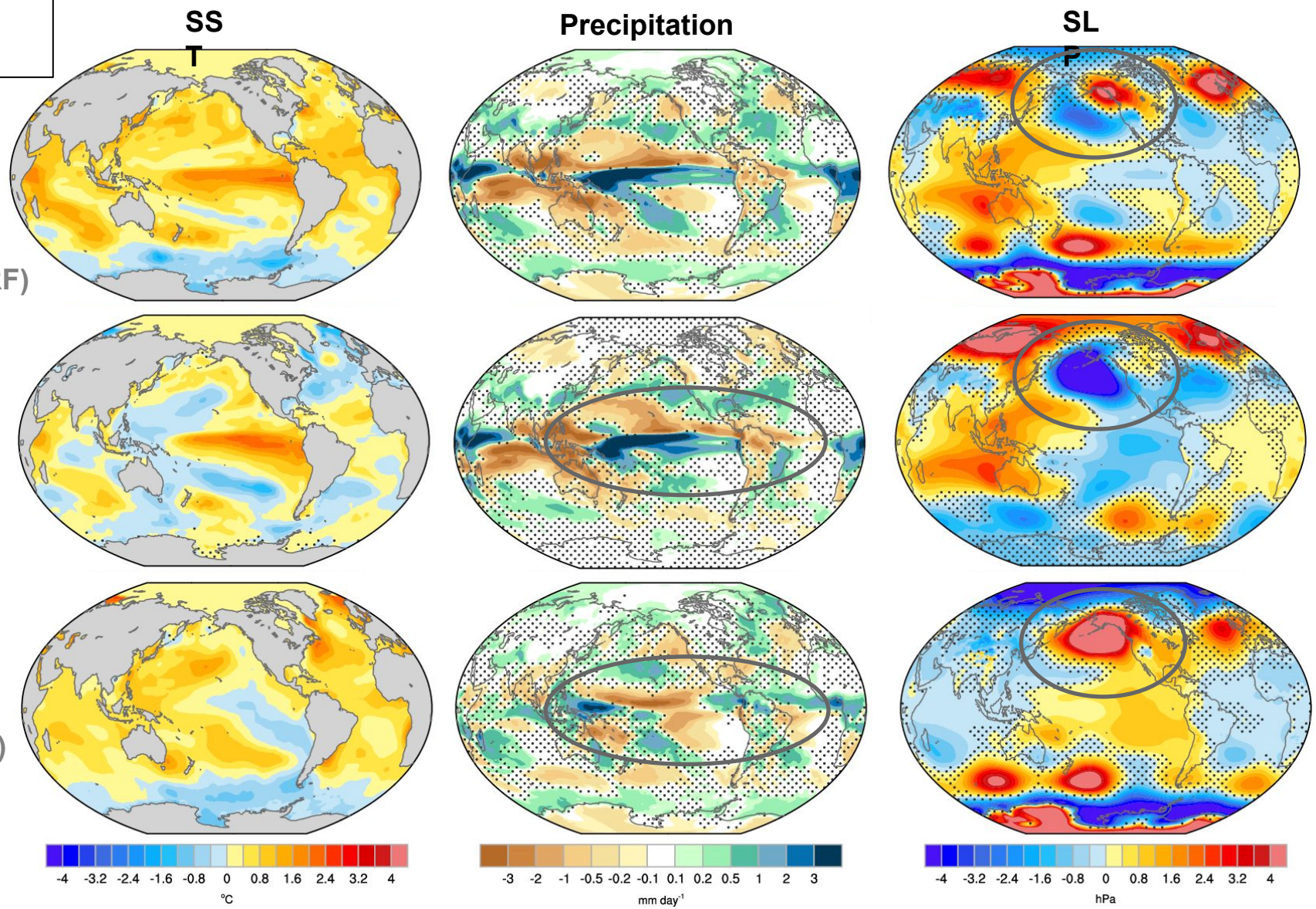






NCAR CGD Seminar by Clara Deser (03/05/24):
"Predicting the El Nino of 2023/24 and its climate impacts over North America"
https://www.youtube.com/watch?v=WVXvu8NDW74&t=644s

DJF 2023/24



Summary

- The CESM2 SMYLE prediction system is a freely-available resource for exploring seasonal-to-multiyear Earth system prediction
  - overview manuscript (2022): https://doi.org/10.5194/gmd-15-6451-2022
  - data: https://www.cesm.ucar.edu/working-groups/earth-system-prediction/simulations/smyle/

- Some promising results:
  - ENSO skill, competitive with operational centers, can extend well into Year 2
  - Improvements over CESM1 system (DPLE)
  - Suggestions of potential for extended seasonal predictions of a variety of Earth system fields, including atmosphere, ocean, land, sea ice, & carbon cycle (ocean/land)

- Fills a gap in the CESM hierarchy of prediction systems that span subseasonal to centennial
  - establishes a prediction performance baseline for S2I
  - facilitates broad prediction research by the CESM community

- Could serve as template for internationally-coordinated S2I prediction protocol (WCRP-DCPP)
  - straightforward extension to decadal timescale

Extra Slides

Towards Impacts Predictions

- SMYLE-NOV climatological SST bias
  (1970-2019 climo)

- OBS: ERSSTv5