NCAR
NATIONAL CENTER FOR ATMOSPHERIC RESEARCH

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The CESM Decadal Prediction Large Ensemble & multi-year forecasts of Arctic sea ice

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DEPARTMENT OF ENERGY · UNITED STATES OF AMERICA

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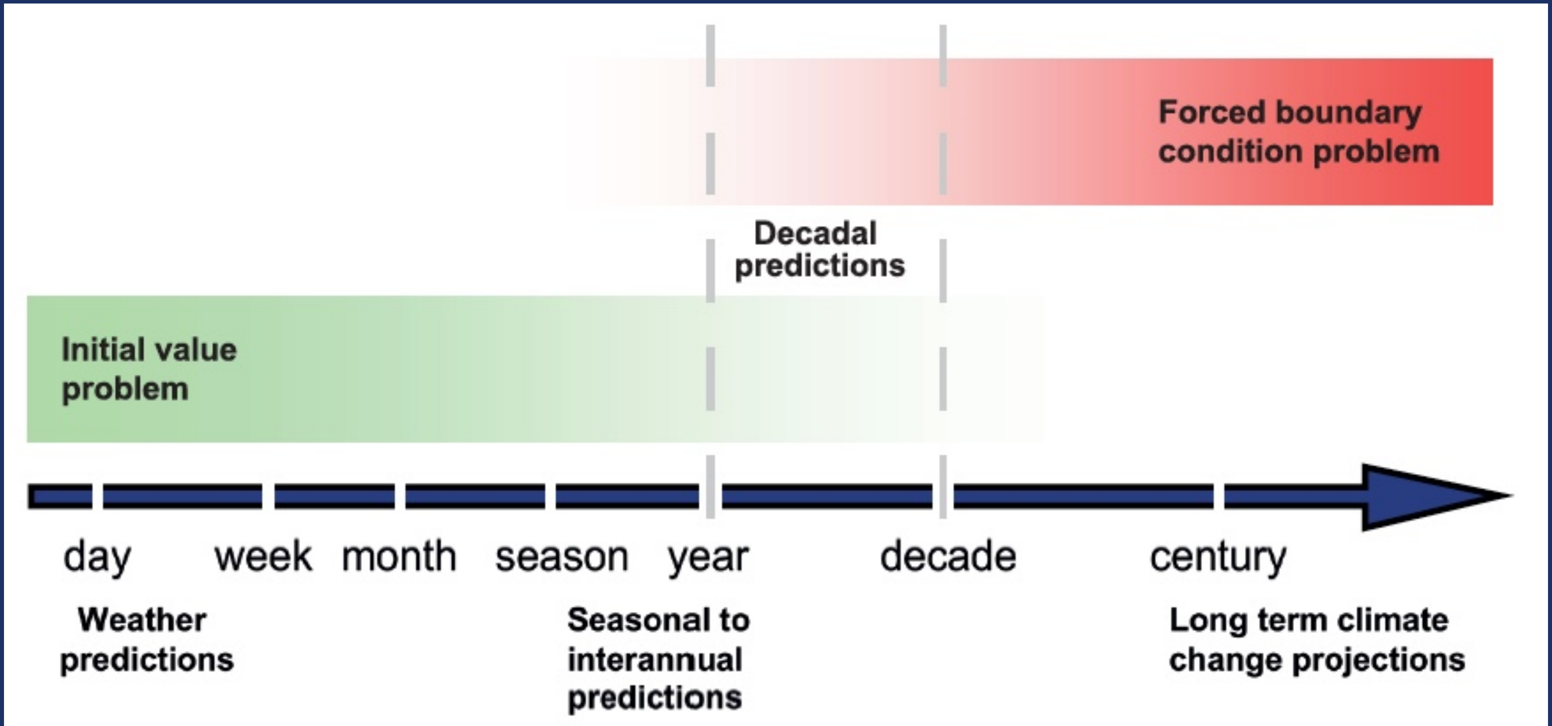
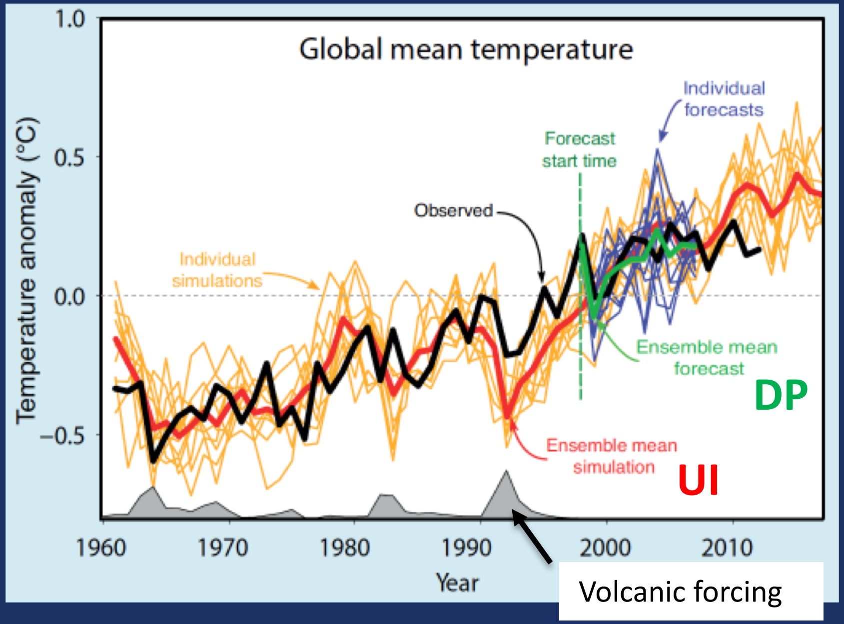
U.S. DEPARTMENT OF COMMERCE

What is decadal climate prediction?

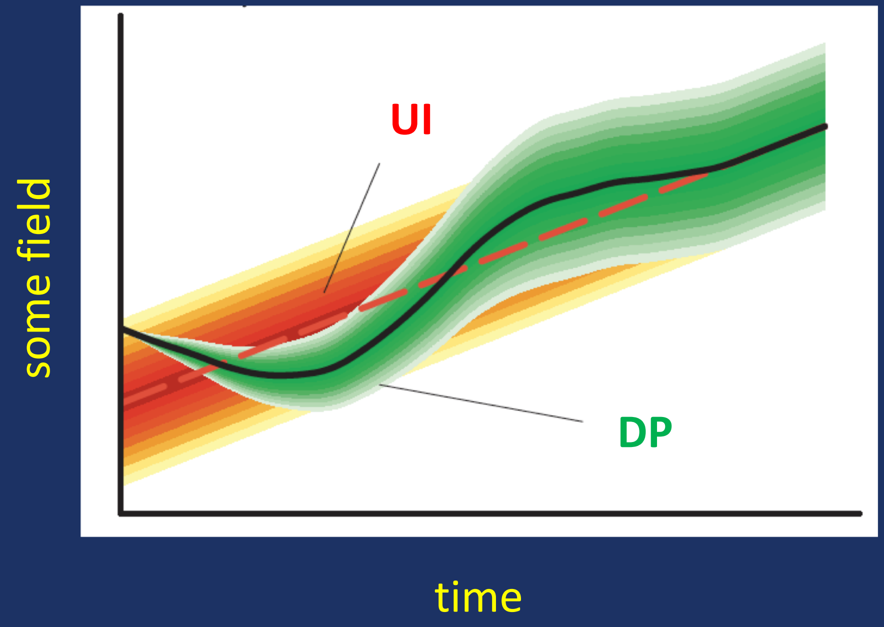


Kirtman & Power, 2013: Near-term Climate Change: Projections and Predictability. *IPCC 5th Assessment Report, Chapter 11.*

Climate Projections vs. Climate Predictions



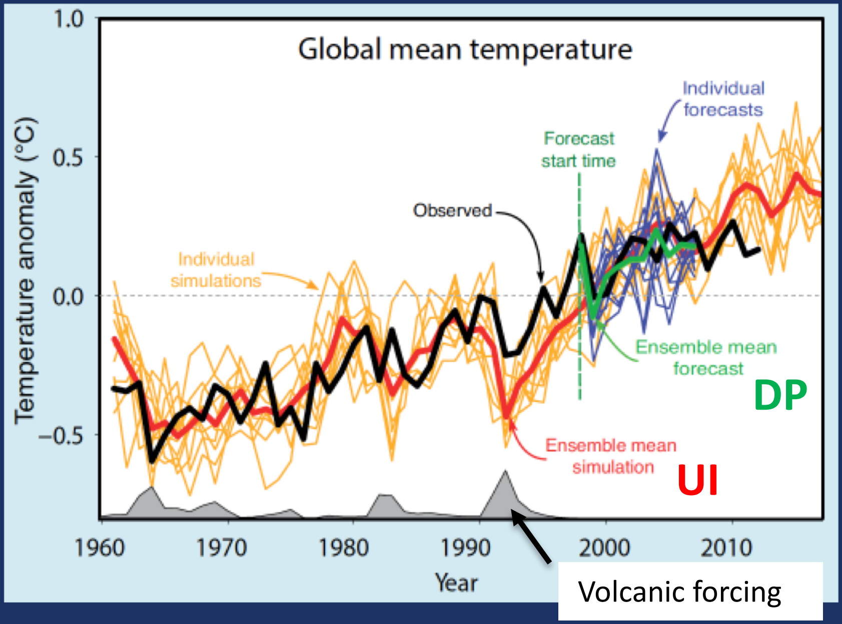
DP: initialized decadal prediction ensemble
UI: "uninitialized" 20th century ensemble

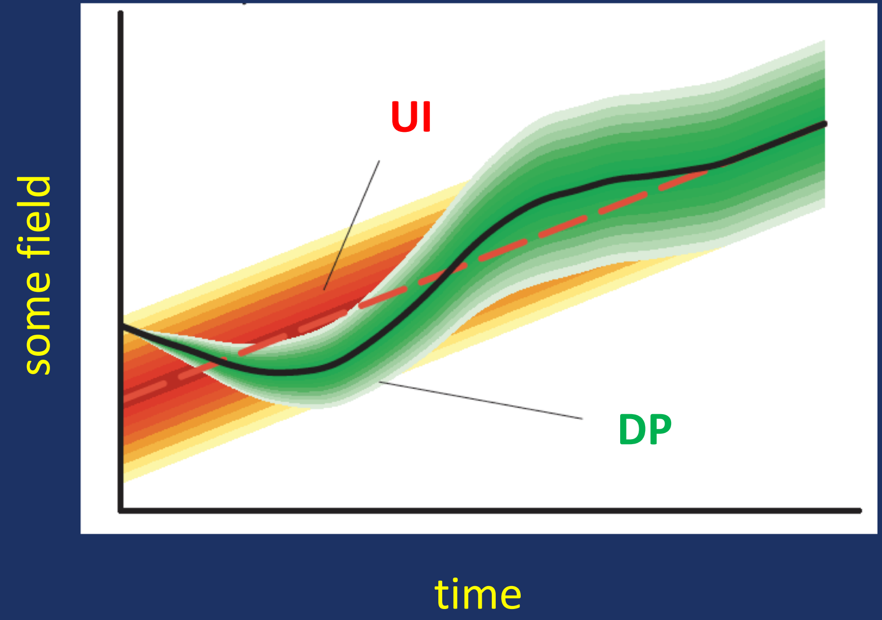


Kirtman & Power, 2013: Near-term Climate Change: Projections and Predictability. *IPCC 5th Assessment Report, Chapter 11.*

Branstator & Teng, 2010: Two limits of initial-value decadal predictability in a CGCM, *J Climate*, 23, 6292–6311.

Climate Projections vs. Climate Predictions



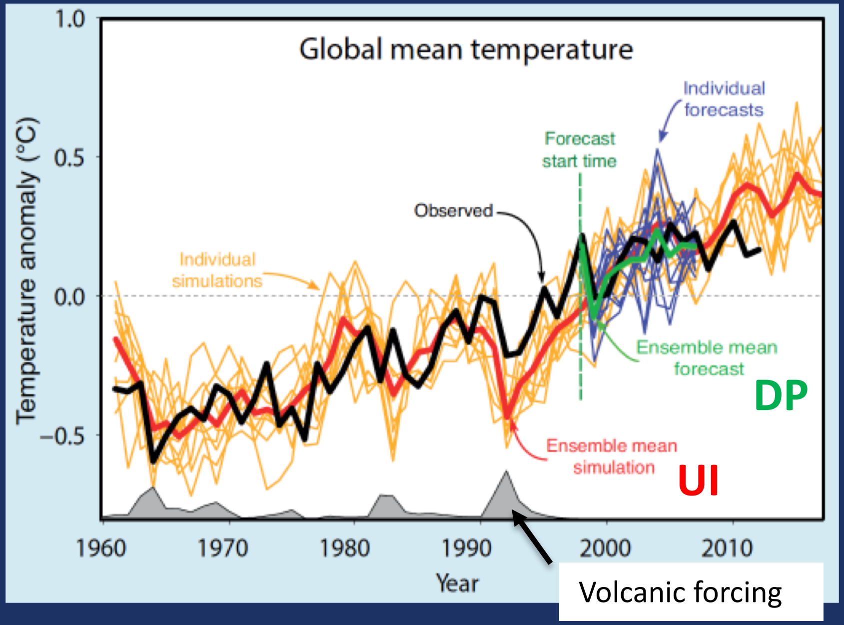


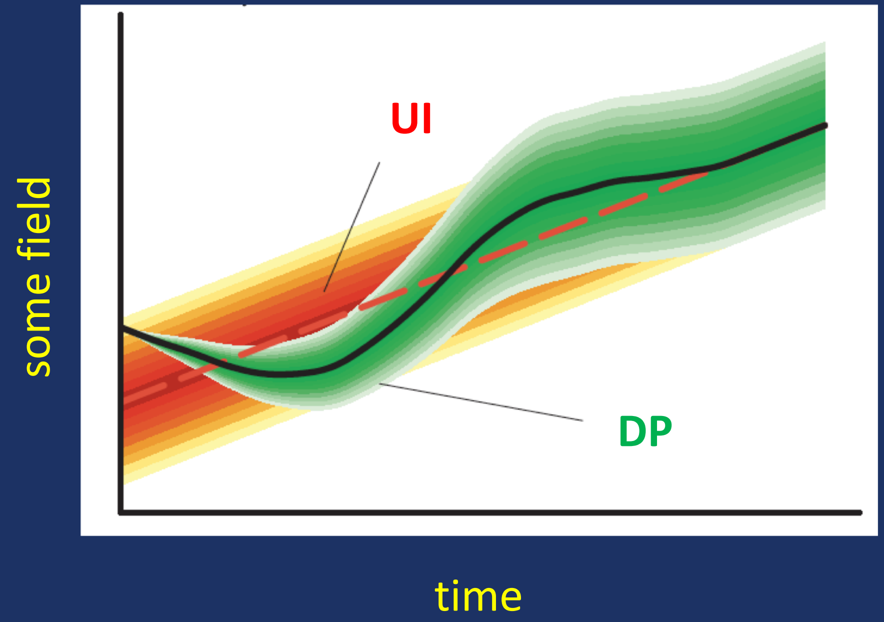
DP: initialized decadal prediction ensemble
UI: "uninitialized" 20th century ensemble

UI ensemble : Earth system response (mean & spread) to external forcings. → "historical/projection runs"

DP ensemble : Earth system response to external forcings **AND** internal processes associated with initialization. → "hindcast/forecast runs"

Climate Projections vs. Climate Predictions





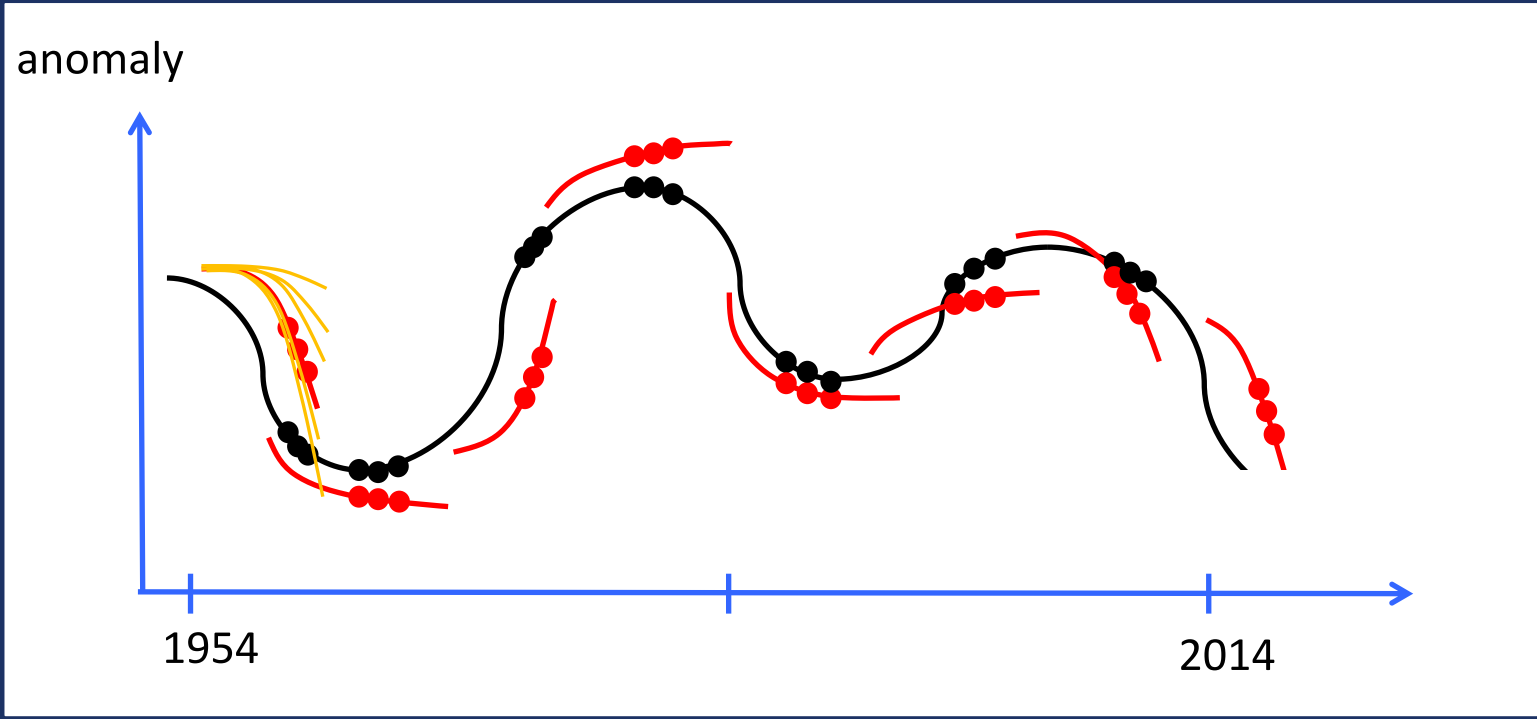
Both ensembles (UI and DP) are needed to fully understand the mechanisms underpinning Earth system prediction. E.g., To what extent does initialization improve near-term regional climate outlooks?

Larger ensembles yield better resolved climate PDFs for probabilistic skill assessment.

DP Skill Assessment

DP hindcast ensemble mean (H)
"observations" (O)

drift-adjusted predicted anomalies (LY 5-7)
corresponding O anomalies



$$ACC = \frac{Cov(OH)}{\sqrt{Var(O)Var(H)}}$$

$$MSSS = 1 - \frac{MSE}{MSE_{ref}}$$

$$MSE = \frac{1}{n}\sum_{j=1}^{n}(H_j - O_j)^2$$

Goddard et al., 2013, Clim Dyn, doi: 10.1007/s00382-012-1481-2
Boer et al., 2013, Clim Dyn, doi: 10.1007/s00382-013-1705-0

CESM Decadal Prediction Large Ensemble

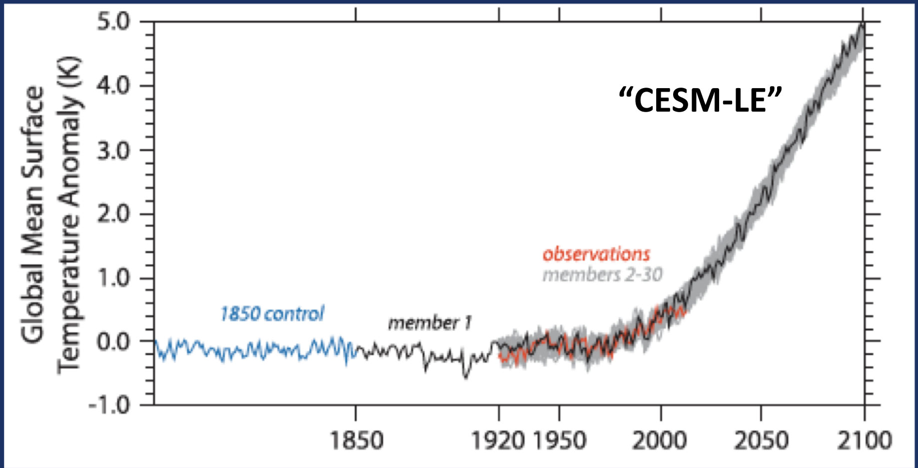
Experiment Name	CCSM4-DP	CESM-DPLE
Model -atm -ocn -ice -lnd	CCSM4 CAM4 (FV 1°, 26lvl) POP2 (1°, 60lvl) CICE4 (1°) CLM4	**CESM1.1** **CAM5** (FV 1°, **30lvl**) POP2 (1°, 60lvl) **w/ BGC** CICE4 (1°) CLM4
Uninitialized Ensemble (UI)	6-member CCSM4 20th century ensemble (Meehl et al., 2012)	**40-member CESM 20th century Large Ensemble** (Kay et al., 2015)
Forcing	-2005: CMIP5 historical 2006-: CMIP5 RCP 4.5	-2005: CMIP5 historical 2006-: CMIP5 **RCP 8.5**
Initialization -method -atm -ocn -ice -lnd	 full field UI CORE-forced FOSI CORE-forced FOSI UI	 full field UI **CORE*-forced FOSI** **CORE*-forced FOSI** UI
Ensembles -ensemble size -start dates -ensemble generation -simulation length	 10 annual; Jan. 1st 1955-2014 (N=60) Variable January start days + round-off perturbation of atm initial conditions 120 months	 **40** annual; **Nov. 1st 1954-2015 (N=62)** round-off perturbation of atm initial conditions 122 months

CMIP5-era (2011)

CMIP6-era (2017)

CESM Decadal Prediction Large Ensemble

Experiment Name	CESM-DPLE
Model -atm -ocn -ice -lnd	**CESM1.1 (CESM-LE tag)** **CAM5** (FV 1°, **30lvl**) POP2 (1°, 60lvl) **w/ BGC** CICE4 (1°) CLM4
Uninitialized Ensemble (UI)	**40-member CESM 20th century Large Ensemble** (Kay et al., 2015)
Forcing	-2005: CMIP5 historical 2006-: CMIP5 **RCP 8.5**
Initialization -method -atm -ocn -ice -lnd	 full field UI **CORE*-forced FOSI** **CORE*-forced FOSI** UI
Ensembles -ensemble size -start dates -ensemble generation -simulation length	 **40** annual; **Nov. 1st 1954-2015 (N=62)** round-off perturbation of atm initial conditions 122 months



Kay et al., 2015: The Community Earth System Model (CESM) Large Ensemble Project: A Community Resource for Studying Climate Change in the Presence of Internal Climate Variability, *BAMS*, doi:10.1175/BAMS-D-13-00255.1.

Comparing CESM-DPLE to CESM-LE isolates the impact of initialization on hindcast skill.

CESM Decadal Prediction Large Ensemble

Experiment Name	CESM-DPLE
Model -atm -ocn -ice -lnd	**CESM1.1 (CESM-LE tag)** **CAM5** (FV 1°, **30lvl**) POP2 (1°, 60lvl) **w/ BGC** CICE4 (1°) CLM4
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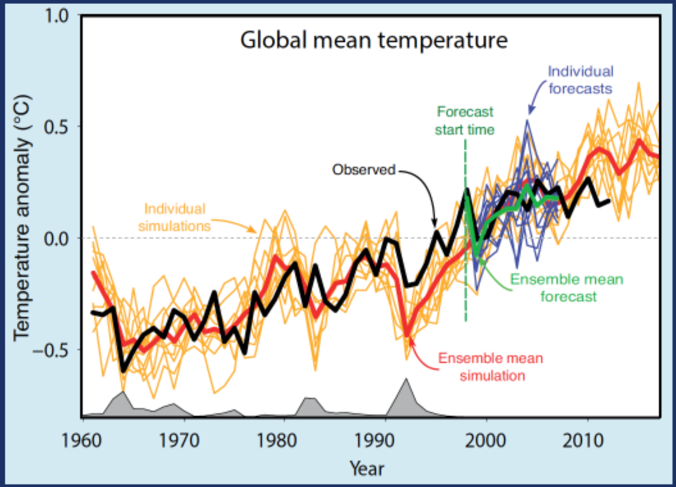
Ensembles -ensemble size -start dates -ensemble generation -simulation length	 **40** annual; **Nov. 1st 1954-2015 (N=62)** round-off perturbation of atm initial conditions 122 months

Includes historical volcanic aerosol forcing, following standard protocol (this allows for more powerful test of the effects of initialization when comparing to the UI ensemble).



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Ensembles -ensemble size -start dates -ensemble generation -simulation length	 **40** annual; **Nov. 1st 1954-2015** (**N=62**) round-off perturbation of atm initial conditions 122 months

ATM & **LND** components initialized from a CESM-LE historical run.

OCN & **ICE** components initialized from a forced ocean—sea-ice (FOSI) simulation spanning 1948-2015 ➔ "FOSI" or "CORE"

CESM Decadal Prediction Large Ensemble

Experiment Name	CESM-DPLE
Model -atm -ocn -ice -lnd	**CESM1.1 (CESM-LE tag)** **CAM5** (FV 1°, **30lvl**) POP2 (1°, 60lvl) **w/ BGC** CICE4 (1°) CLM4
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Initialization -method -atm -ocn -ice -lnd	 full field UI **CORE*-forced FOSI** **CORE*-forced FOSI** UI
Ensembles -ensemble size -start dates -ensemble generation -simulation length	 **40** annual; **Nov. 1st 1954-2015** (**N=62**) round-off perturbation of atm initial conditions 122 months

Ensemble size 40, comparable to CESM-LE. Generated via round-off perturbation to ATM initial conditions.

62 distinct ensembles initialized yearly, integrated out 10 years.

~25,000 sim-year experiment!

CESM Decadal Prediction Large Ensemble

http://www.cesm.ucar.edu/projects/community-projects/DPLE/

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/ CESM Projects / Community Projects / DPLE

DPLE | Decadal Prediction Large Ensemble Project

The CESM Decadal Prediction Large Ensemble (DPLE) is a set of simulations carried out at NCAR to support research into near-term Earth System prediction. The DPLE comprises 62 distinct ensembles, one for each of 62 initialization times (November 1 of 1954, 1955, ..., 2014, 2015). For each start date, a 40-member ensemble was generated by randomly perturbing the atmospheric initial condition at the round-off level. The simulations were integrated forward for 122 months after initialization. Observation-based ocean and sea ice initial conditions for the 1954-2015 period were obtained from a reanalysis-forced simulation of the CESM ocean and sea ice models. The initial conditions for the atmosphere and land models were obtained from CESM Large Ensemble (LENS) simulations at corresponding historical times. Full field initialization was used for all component models, and so drift adjustment prior to analysis is generally recommended (e.g., see here).

The DPLE was run using the same CESM code base, configuration details, component resolutions (nominally 1-degree in both atmosphere and ocean), and external forcing datasets as for the CESM LENS project. DPLE therefore represents the "initialized" complement to the LENS simulations. Steve Yeager [yeager@ucar.edu] at NCAR is the primary contact for DPLE-related inquiries. Nan Rosenbloom and Gary Strand were instrumental in the setup, running, and post-processing of the DPLE simulations, with assistance from Sheri Mickelson, Alice Bertini, Jim Edwards, and Shiquan Su. The initial 10 members were made possible by a Department of Energy award of computer time on machines at the National Energy Research Scientific Computing Center (NERSC). The additional 30 members were completed in early 2017 thanks to a CISL Accelerated Scientific Discovery award on Cheyenne.

The DPLE is a CESM community project, and the output from the simulations is available to anyone who is interested. Monthly, daily, and 6-hourly outputs are archived on the NCAR HPSS system and accessible from the Earth System Grid (http://www.earthsystemgrid.org) as single variable timeseries. A list of available output fields can be found here. (NOTE: Not all fields are available for all 40 members. See Known Issues link for further details.) If you are interested in analyzing the CESM-DPLE, we kindly ask that you provide a short description of your proposed research focus to Steve Yeager [yeager@ucar.edu] to be included in the list of ongoing projects (see sidebar).

An overview article describing the DPLE has been published in the Bulletin of the American Meteorological Society:

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, Bulletin of the American Meteorological Society, , doi: .

CESM Project

CESM is a fully-coupled, community, global climate model that provides state-of-the-art computer simulations of the Earth's past, present, and future climate states.

CESM is sponsored by the National Science Foundation (NSF) and the U.S. Department of Energy (DOE). Administration of the CESM is maintained by the Climate and Global Dynamics Laboratory (CGD) at the National Center for Atmospheric Research (NCAR).

DPLE Community Project

- Project Description
- Simulation Details
- Diagnostics
- Data Sets Available to the Community
- Publications
- On-Going Research Projects
- Known Issues

Yeager et al., 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 Meteor Soc*, in press, doi:10.1175/BAMS-D-17-0098.1.

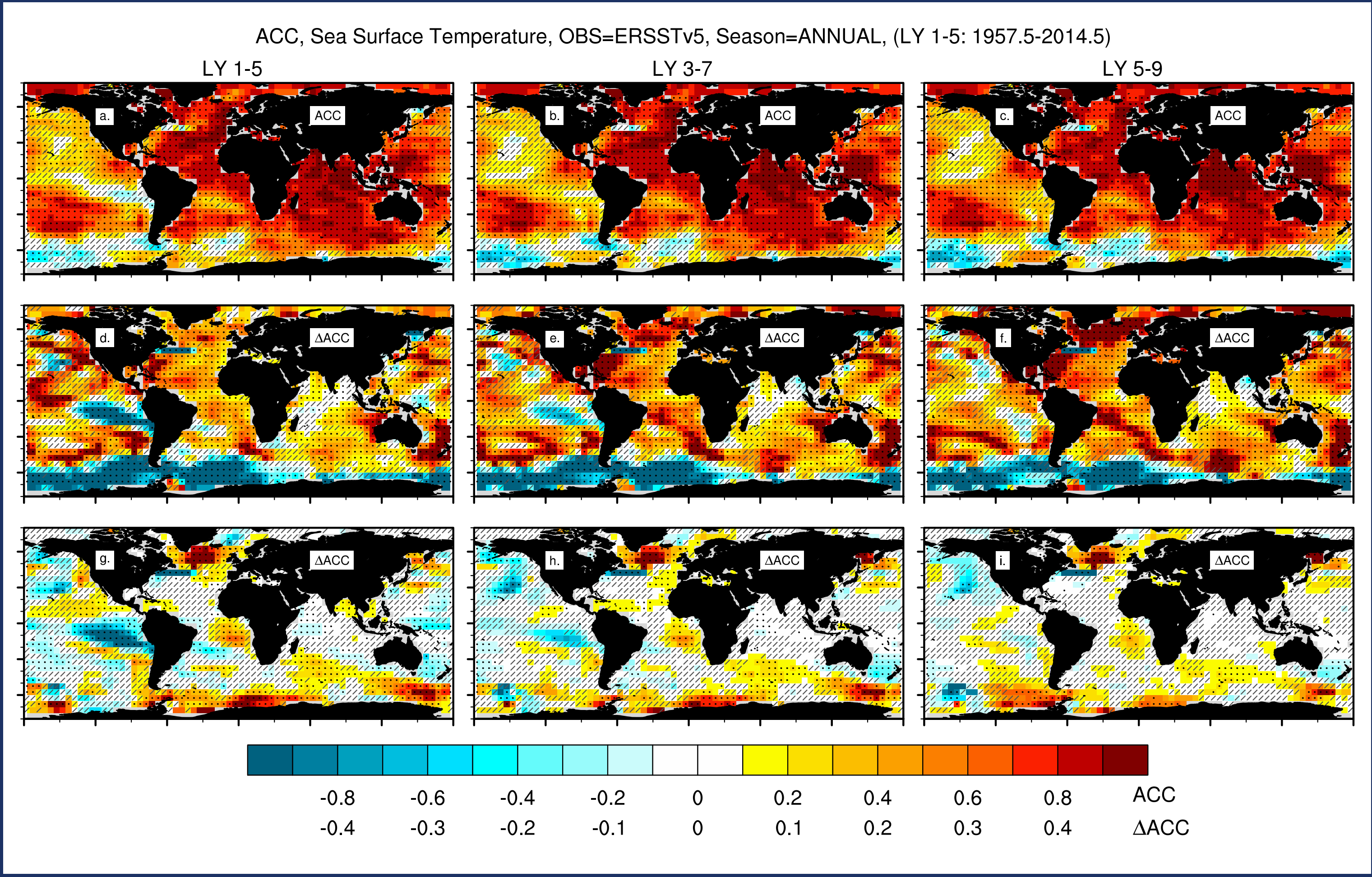
CESM-DPLE: Annual SST Skill

(OBS = ERSSTv5)

➔ Anomaly correlation coefficient (ACC)

➔ Skill improvement over persistence (ΔACC)

➔ Skill improvement over UI (ΔACC)



(Yeager et al. 2018)

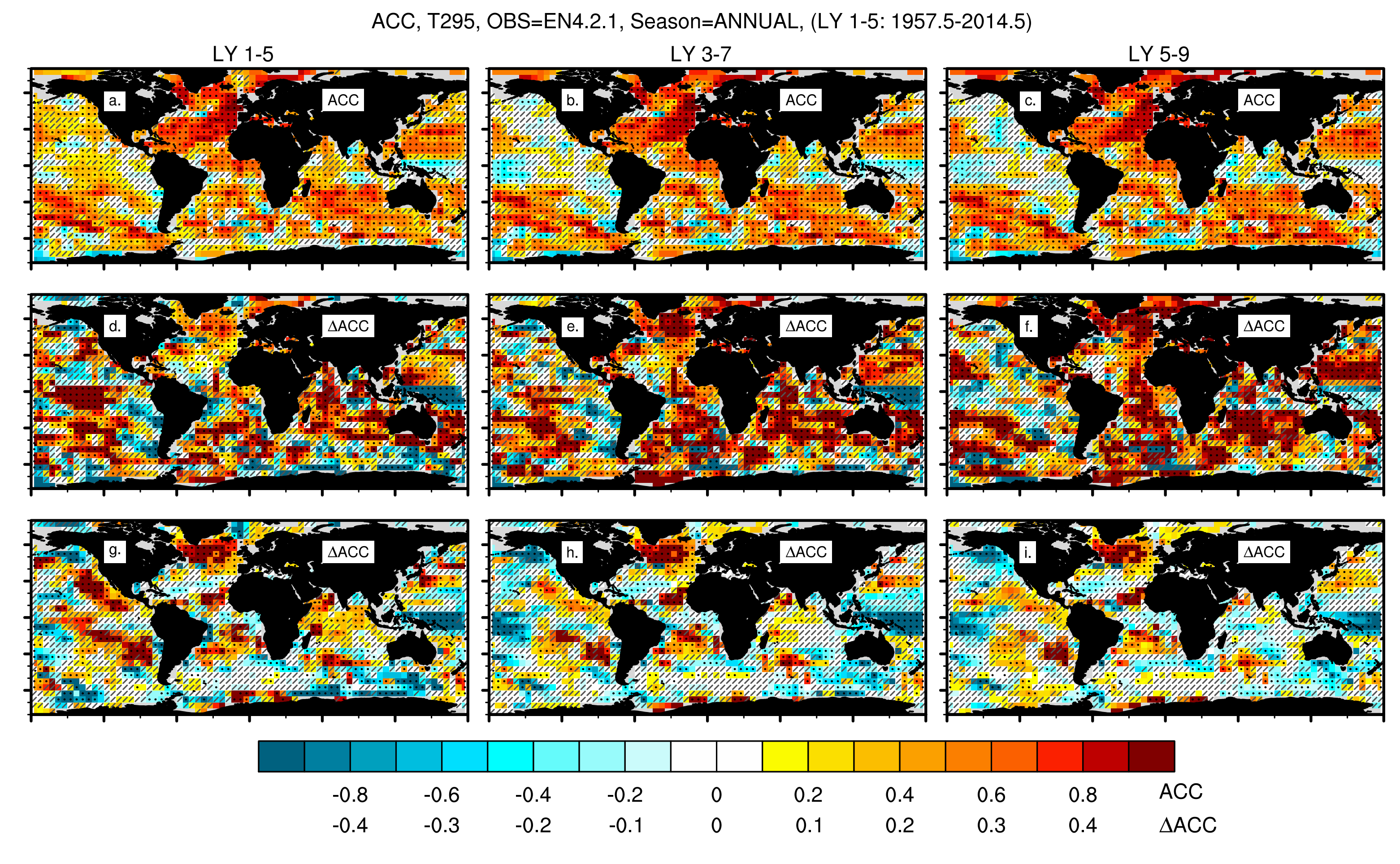
CESM-DPLE: Annual T295 Skill

(OBS = UKMO EN4)

→ Anomaly correlation coefficient (ACC)

→ Skill improvement over persistence (ΔACC)

→ Skill improvement over UI (ΔACC)



(Yeager et al. 2018)

- Skillful prediction of NATL SST associated with skillful prediction of upper ocean heat content

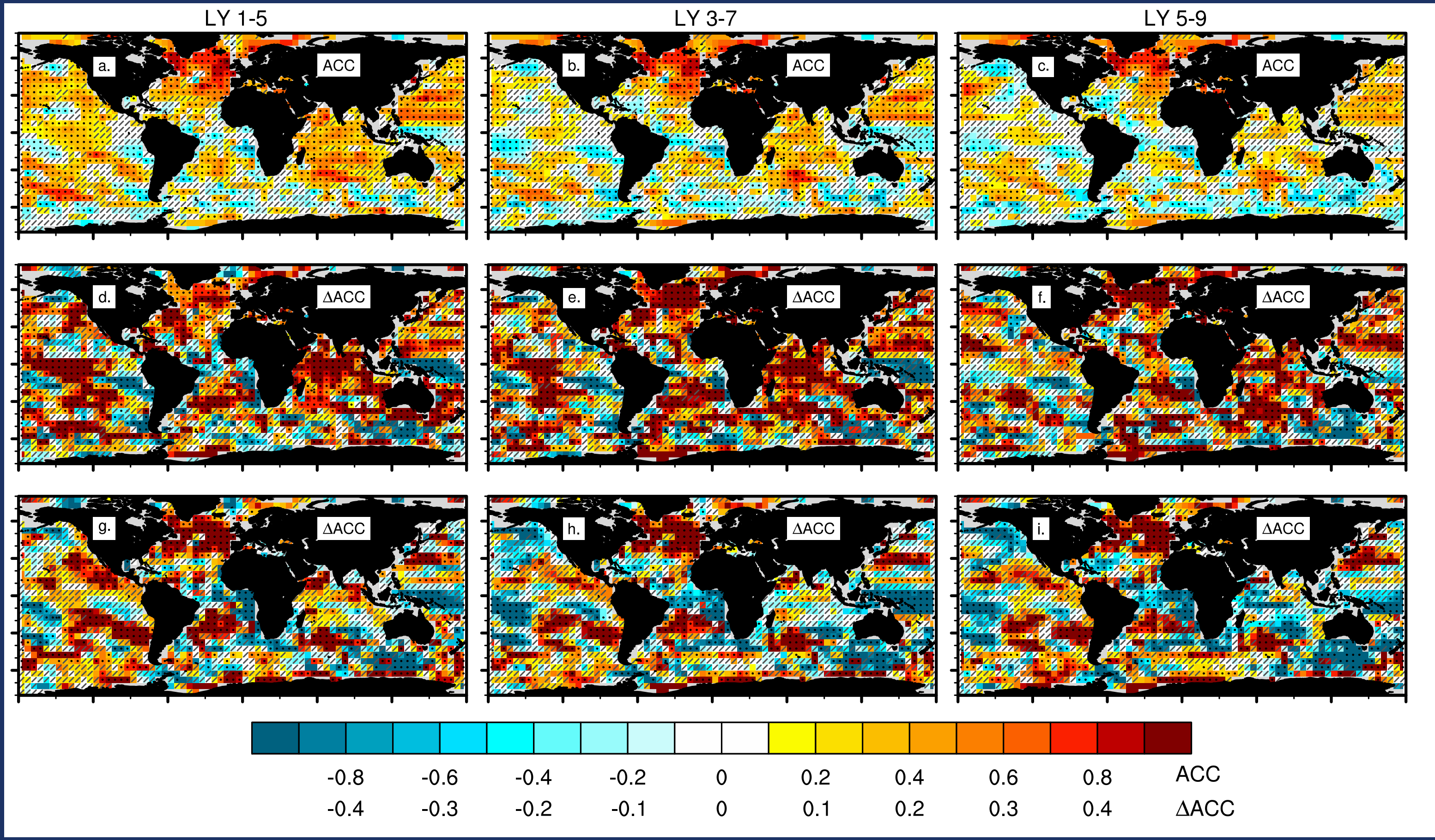
CESM-DPLE: Annual T295 Skill (detrended)

(OBS = UKMO EN4)

➔ Anomaly correlation coefficient (ACC)

➔ Skill improvement over persistence (ΔACC)

➔ Skill improvement over UI (ΔACC)



(Yeager et al. 2018)

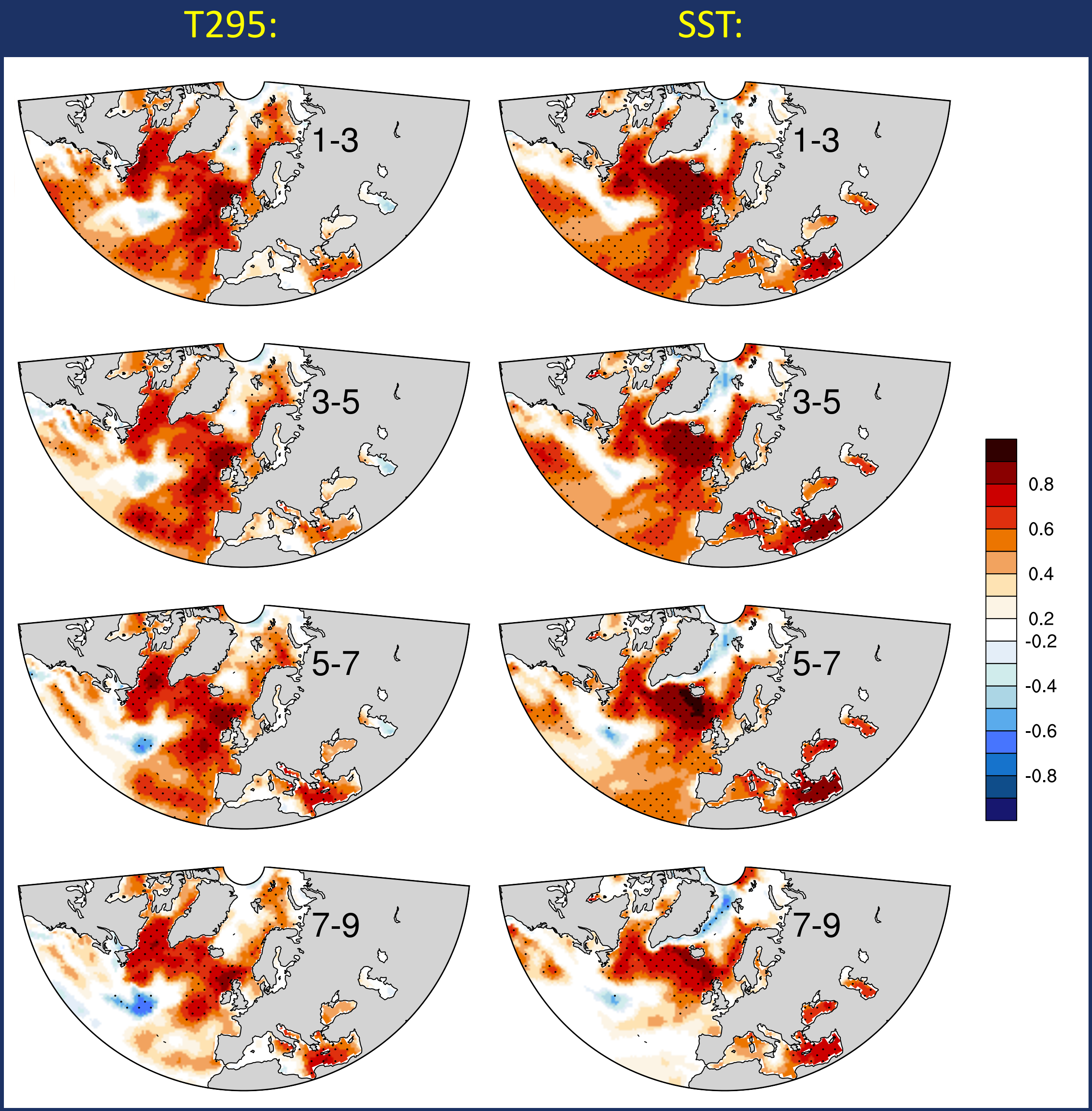
- Skillful prediction of NATL SST associated with skillful prediction of upper ocean heat content

CESM-DPLE: Annual T295/SST Skill (detrended)

ACC(DP,OBS)

(OBS = Met Office EN4 & HadISST)

(detrended 3-year means)



CESM-DPLE: Annual T295/IFRAC Skill (detrended)

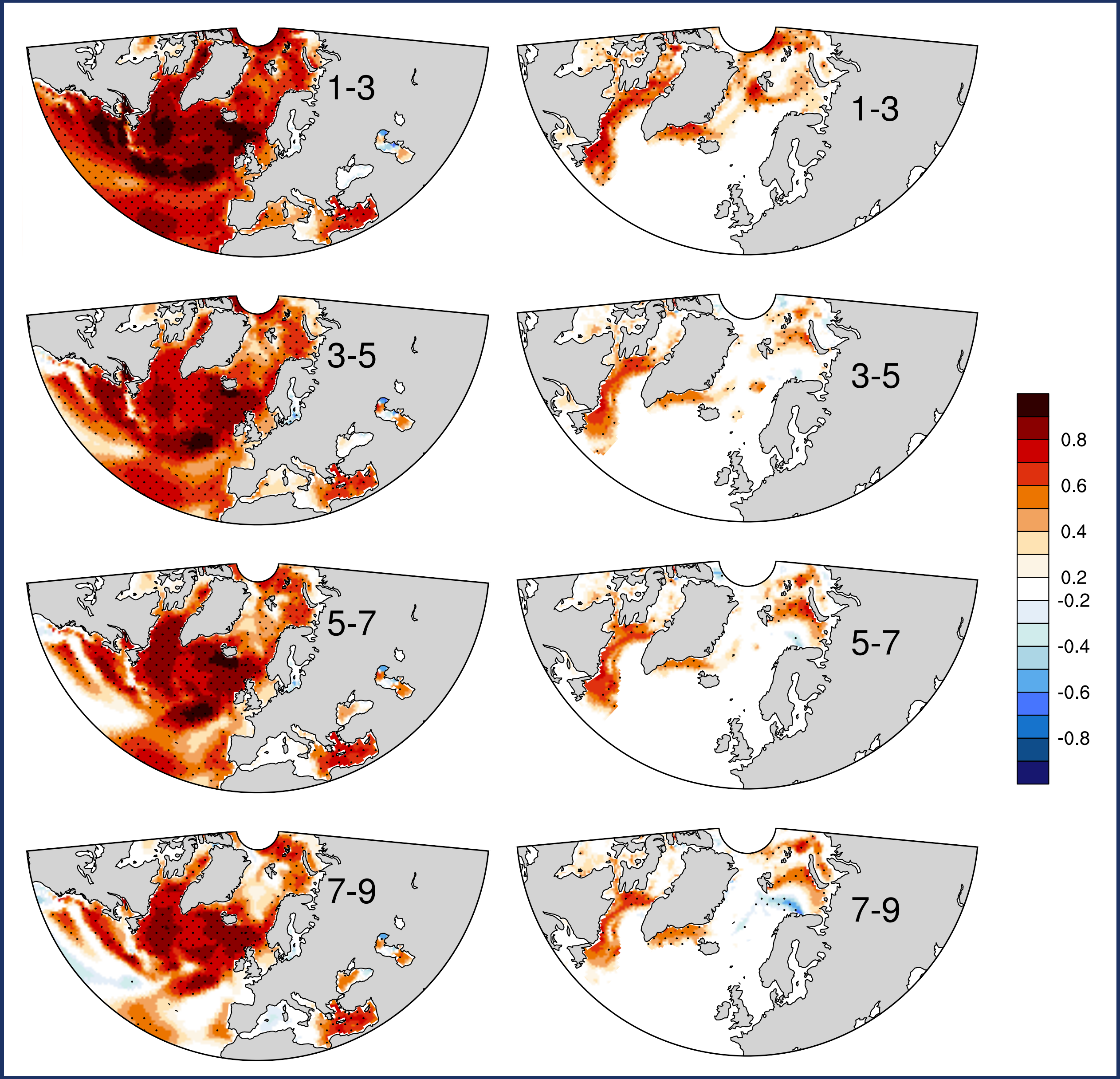
T295:

JFM Ice Fraction:

ACC(DP,CORE)

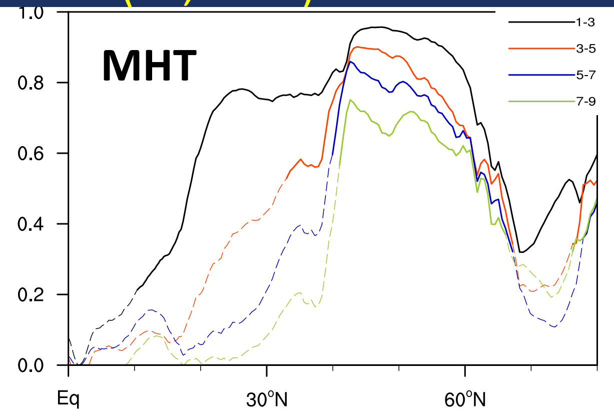
High "potential predictability" (verified against CORE rather than observed data)

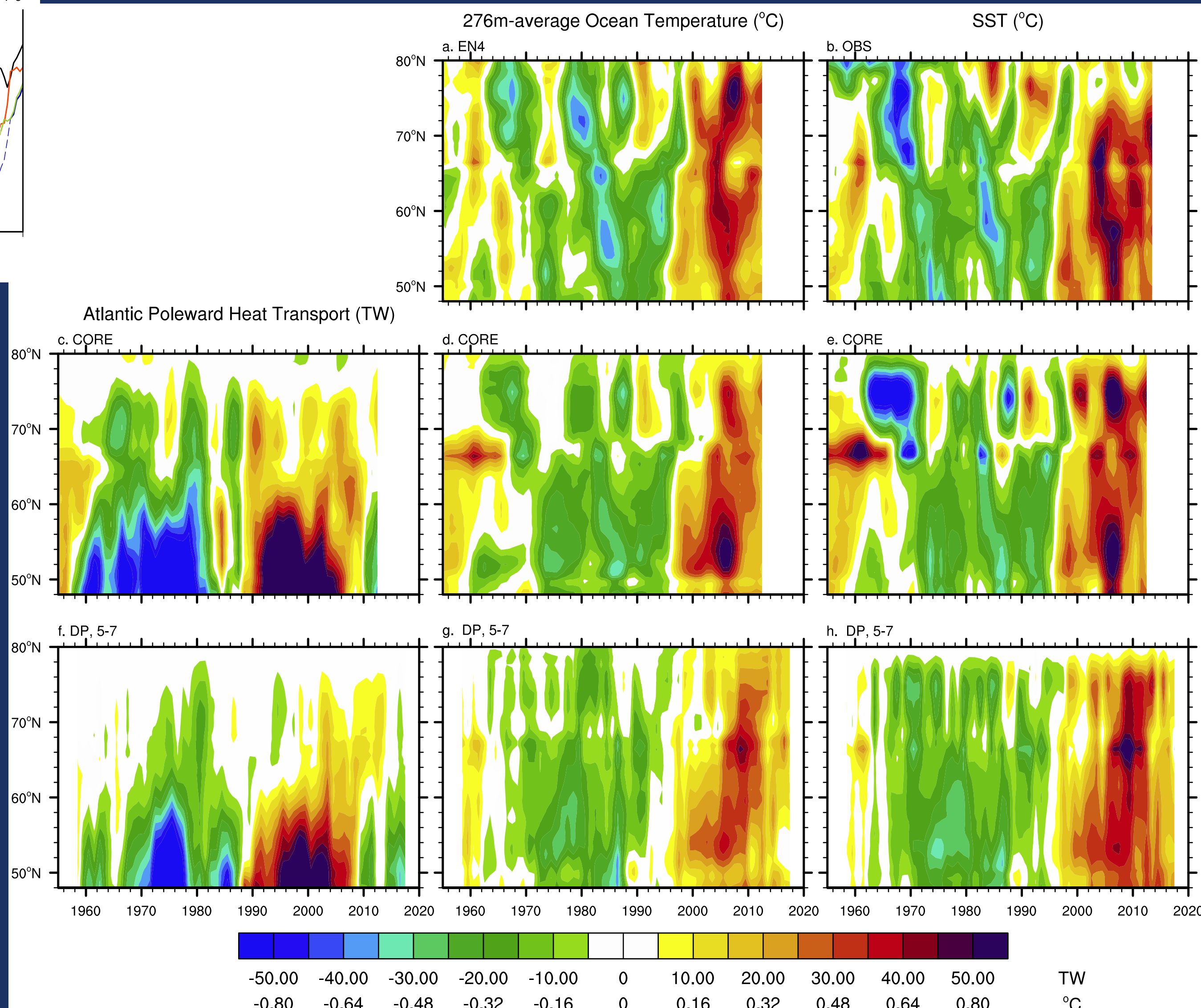
(detrended 3-year means)



Predicting Atlantic Ocean Heat Transport into the Arctic

ACC(DP,CORE)

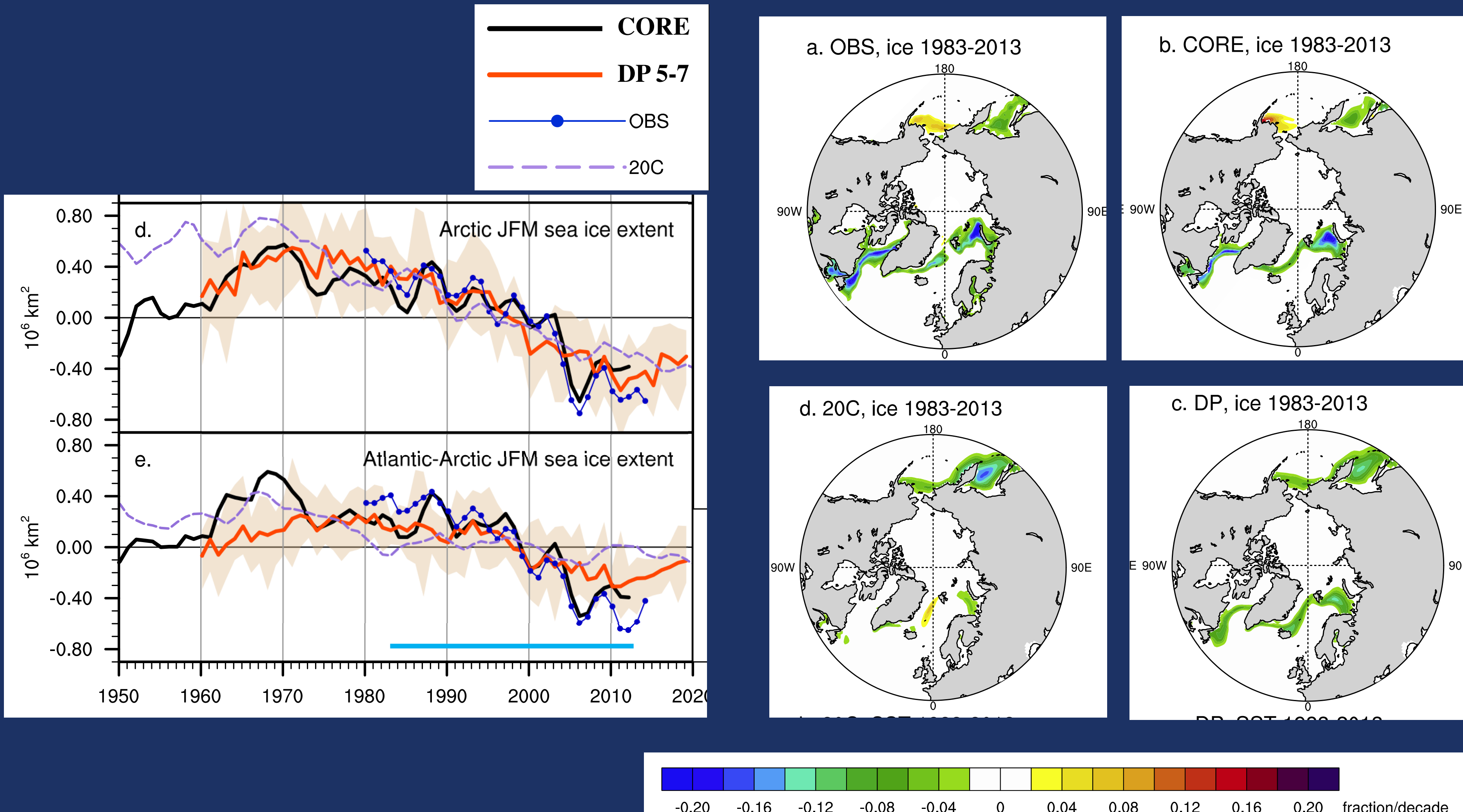




(Yeager et al., 2015)

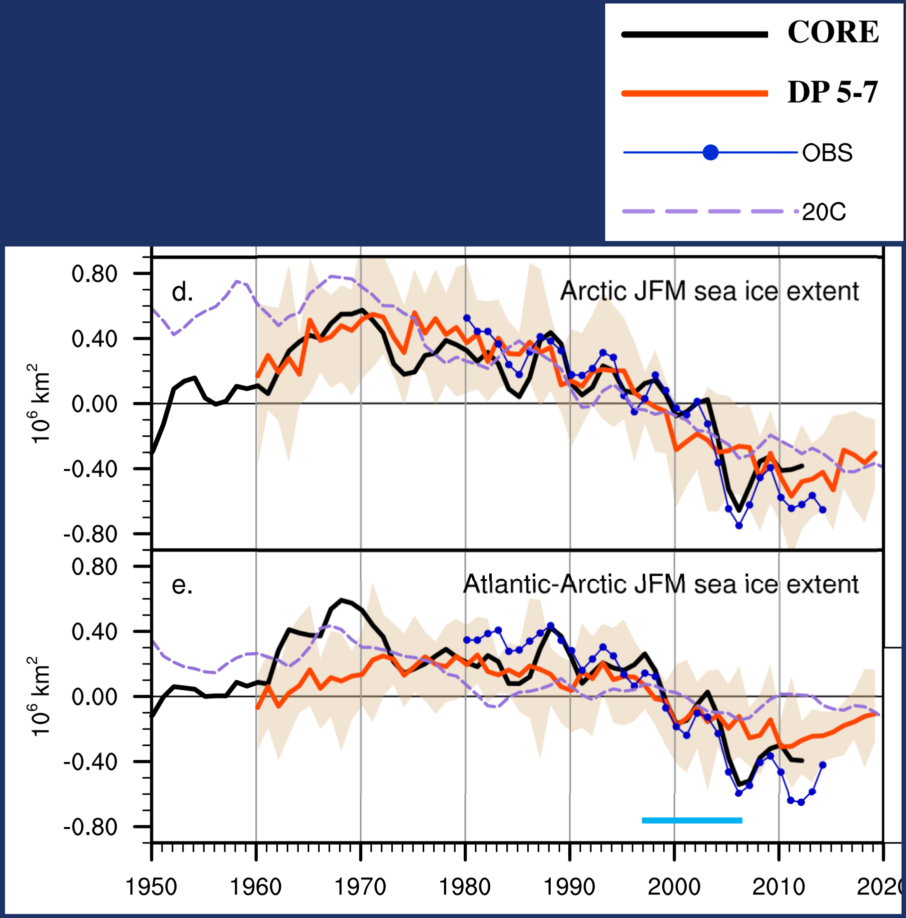
Predicting Winter Sea Ice Trends

30-year trends

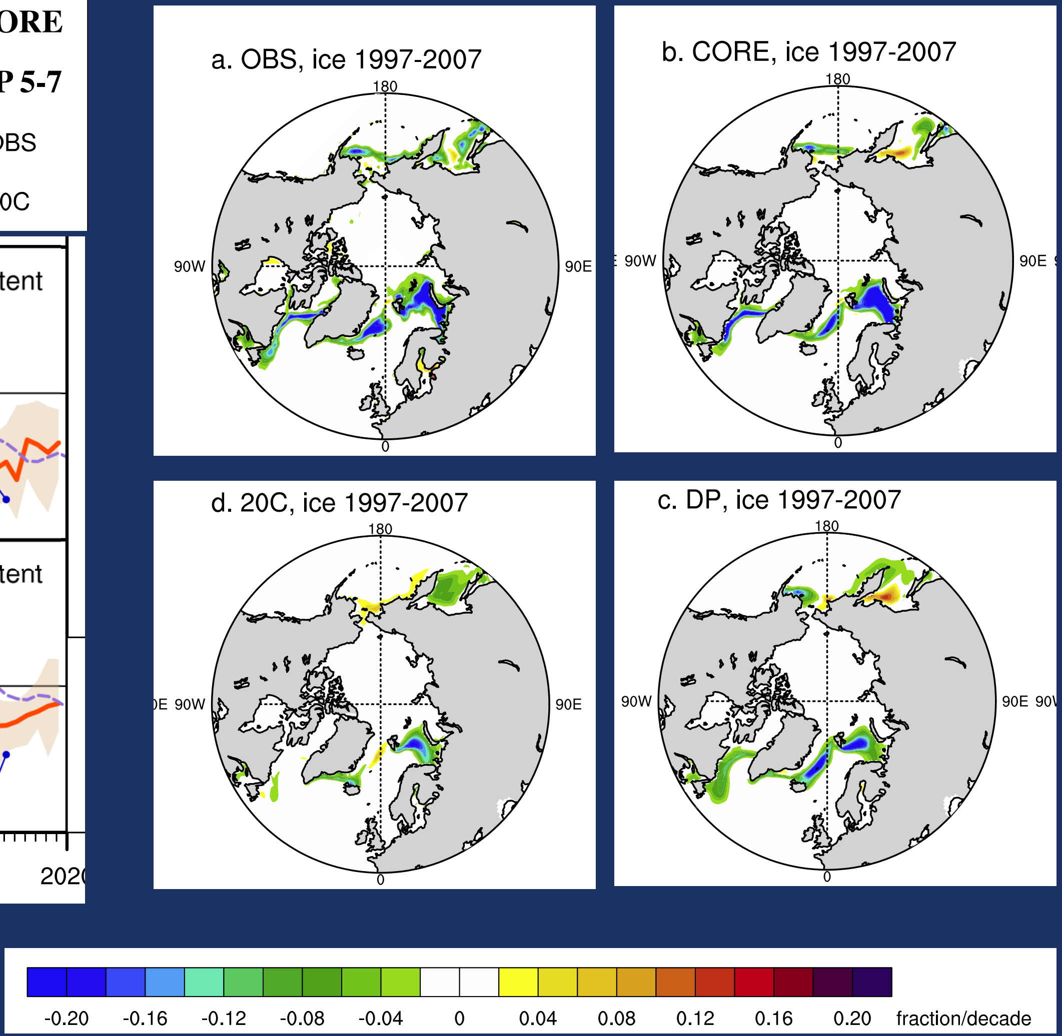


Yeager, Karspeck, and Danabasoglu, 2015: Predicted slowdown in the rate of Atlantic sea ice loss, *Geophys Res Lett*, doi: 10.1002/2015GL065364.

Predicting Winter Sea Ice Trends

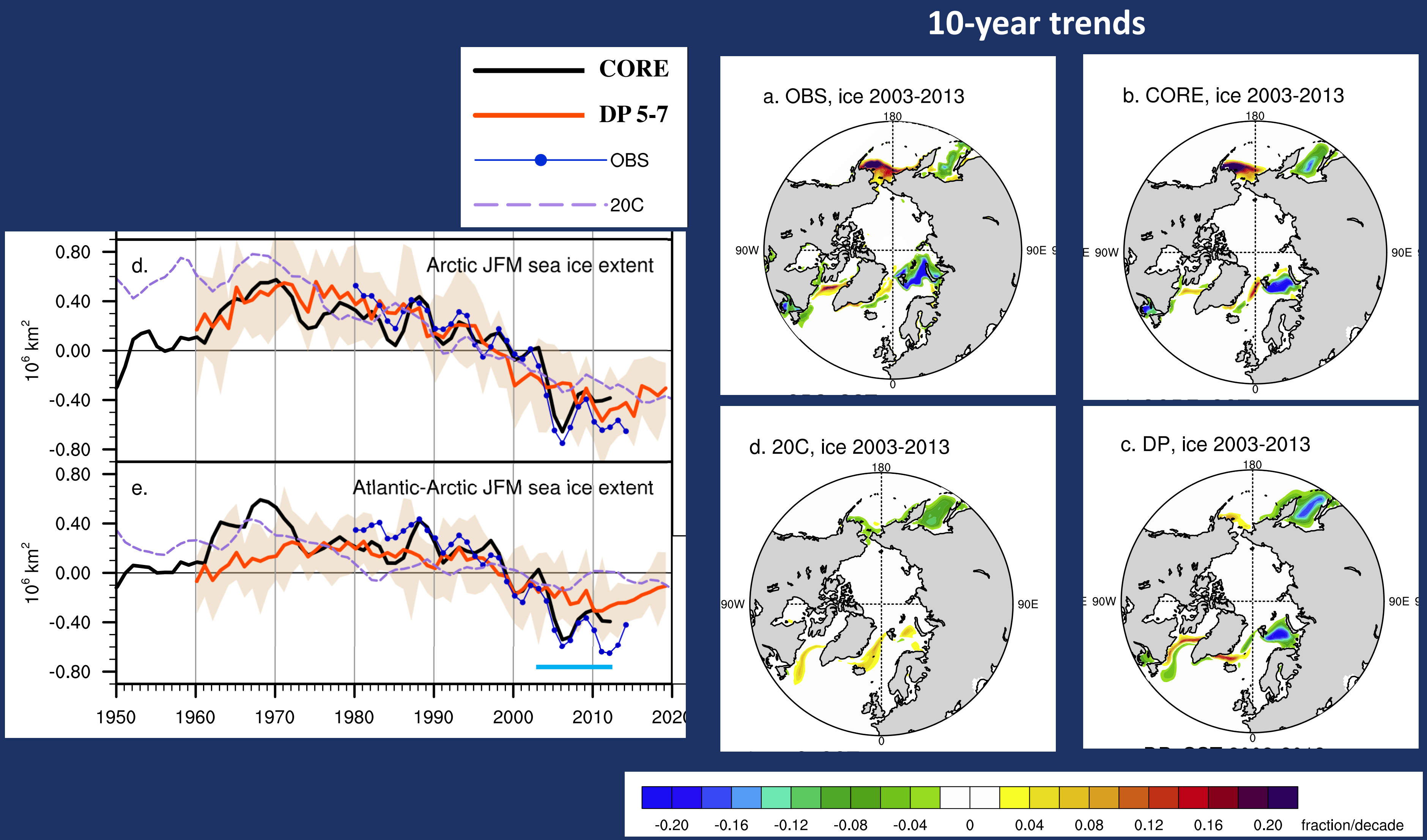


10-year trends



Yeager, Karspeck, and Danabasoglu, 2015: Predicted slowdown in the rate of Atlantic sea ice loss, *Geophys Res Lett*, doi: 10.1002/2015GL065364.

Predicting Winter Sea Ice Trends

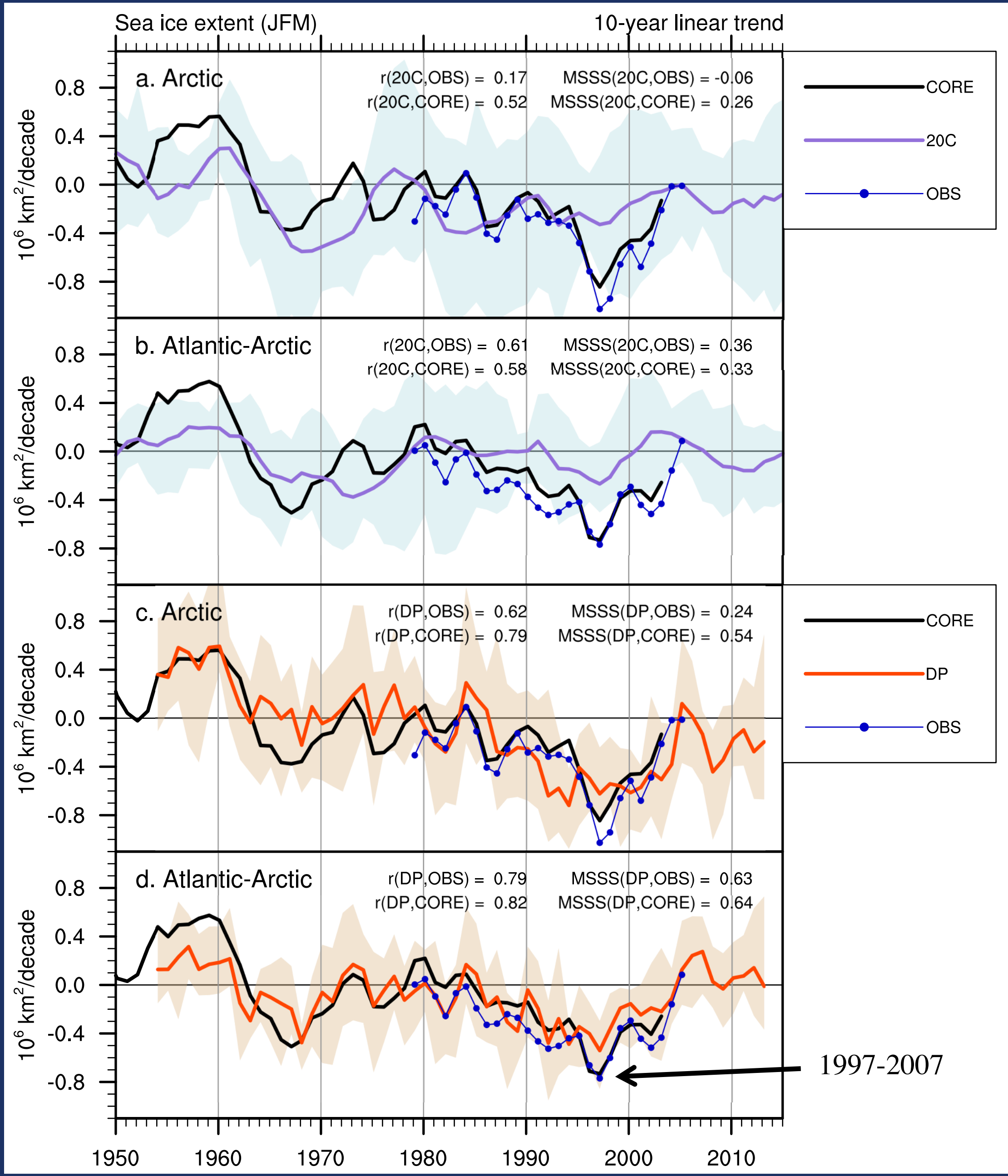


Yeager, Karspeck, and Danabasoglu, 2015: Predicted slowdown in the rate of Atlantic sea ice loss, *Geophys Res Lett*, doi: 10.1002/2015GL065364.

Predicting Winter Sea Ice Trends

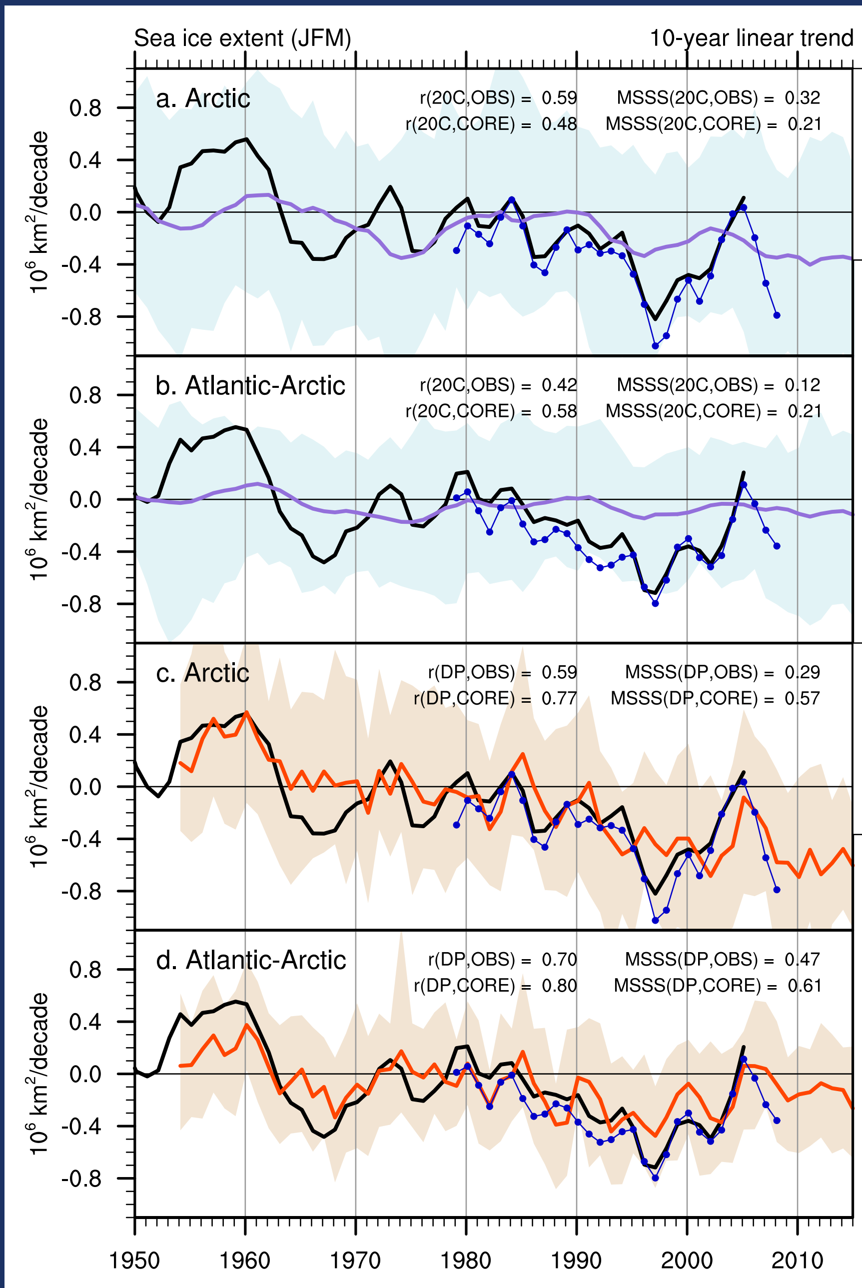
10-year trends
(x-axis = start year of trend)

- **Skillful retrospective prediction of observed decadal trends in Arctic winter sea ice extent.**
- **Significant skill enhancement associated with initialization.**
- **Prediction of recent slowdown and suggestion of extended future hiatus in the rate of Atlantic winter sea ice loss.**

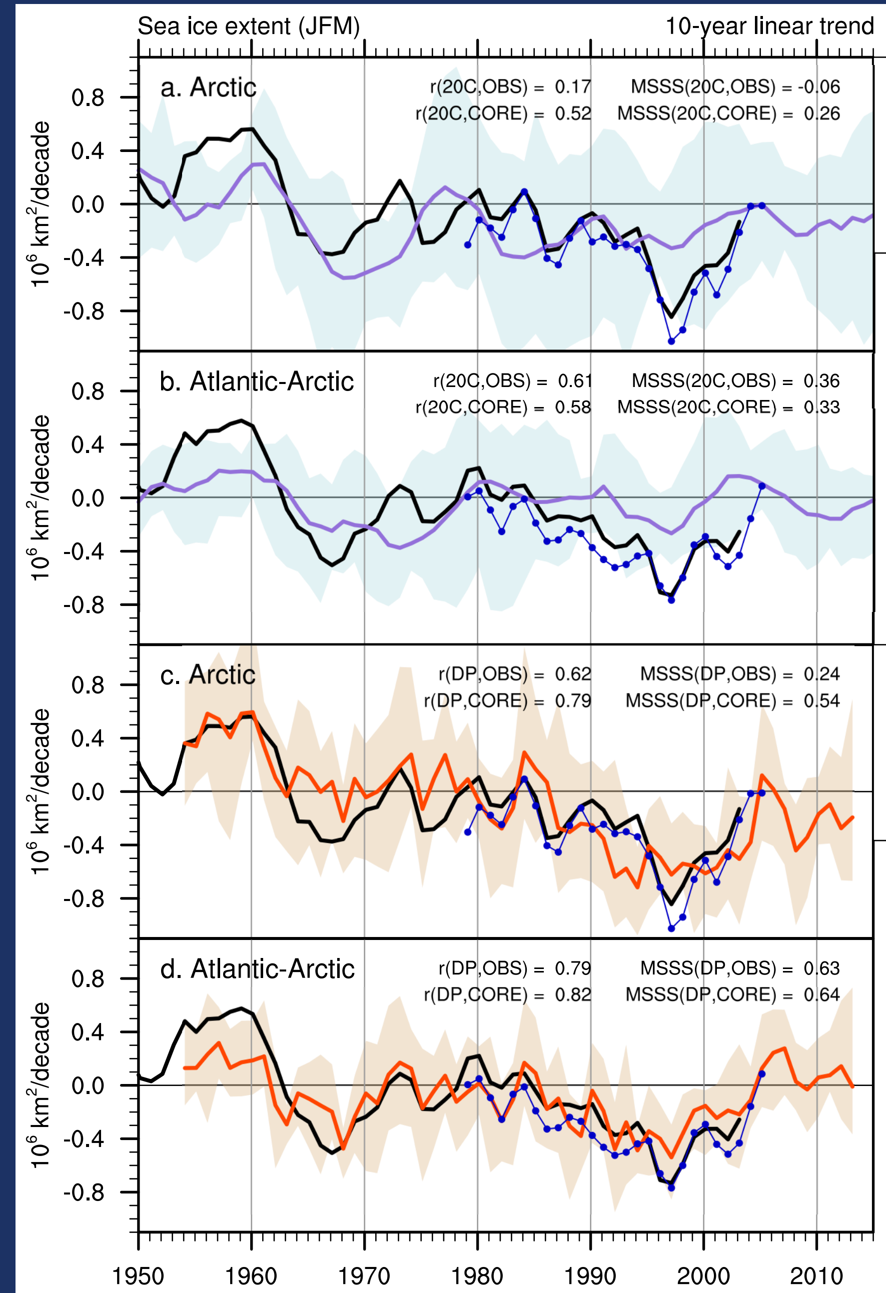


(Yeager et al., 2015)

- 40-member CESM-DPLE
- OBS through JFM 2018



- 10-member CCSM4-DP
- OBS through JFM 2015



https://youtu.be/hc9Lk3d6WSg

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

Summary

- New 40-member decadal prediction simulation set (CESM-DPLE) available for analysis:
  http://www.cesm.ucar.edu/projects/community-projects/DPLE/
  (the initialized complement to the CESM-LE of Kay et al. 2015)

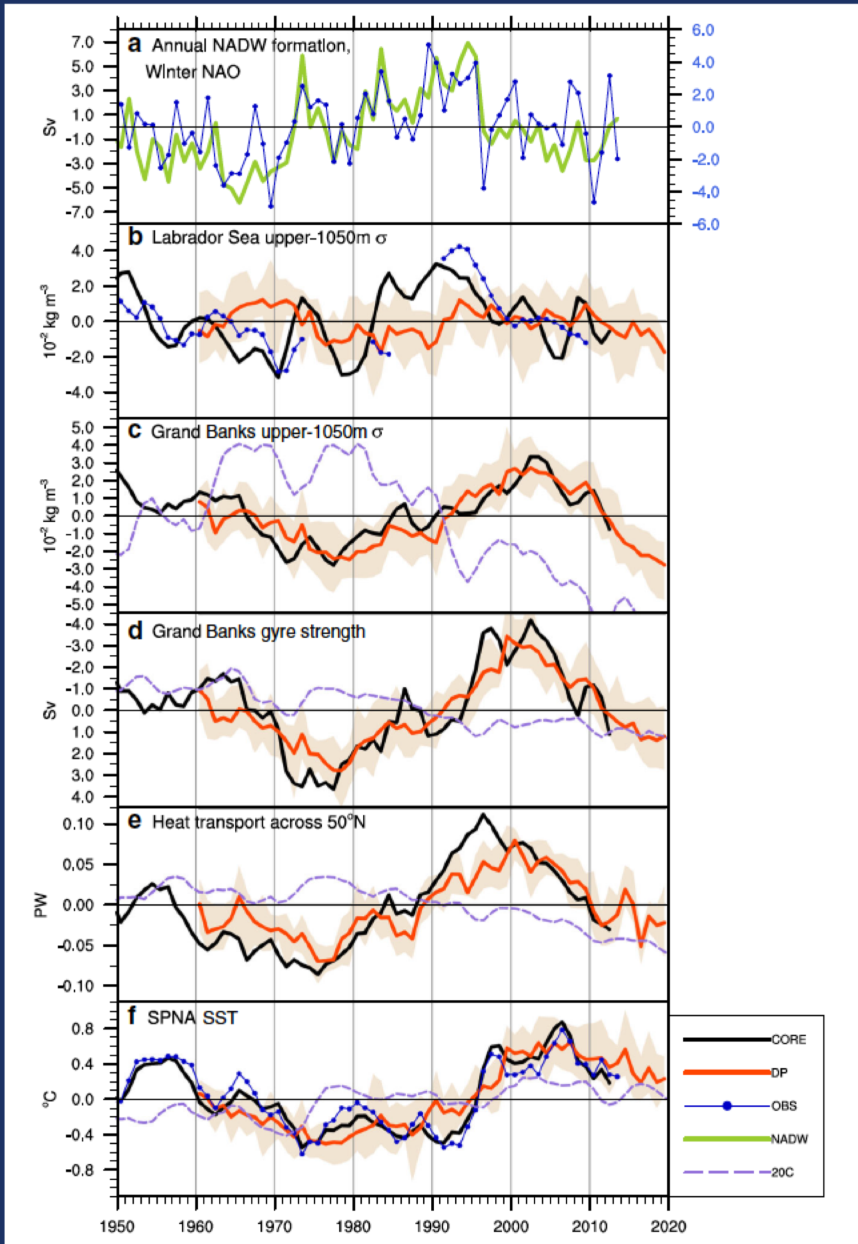
- CESM-DPLE shows good promise for investigations of Arctic decadal predictability associated with high, long-lasting skill at predicting upper ocean heat content in the subpolar Atlantic Ocean, Nordic & Barents Seas.

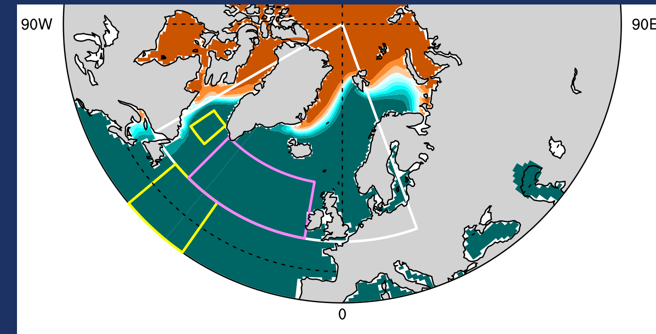
- Initialization results in much improved ability to forecast the magnitude and location of multi-year Arctic sea ice change, particularly in Atlantic sector in winter. Focusing on the (decadal) rate of change helps to:
  1. highlight skill improvement over UI in the context of strong externally-forced trends
  2. isolate predictable (low-frequency, ocean-driven) variability from unpredictable (high-frequency, wind-driven) variability
  3. distinguish initialized skill from that due to simple persistence

- Initialized prediction suggests that we are unlikely to see a return of the extreme rates of winter sea ice loss witnessed in the late 1990s anytime soon. Coming years will provide crucial tests of current DP forecasts.

Extra Slides

Mechanism





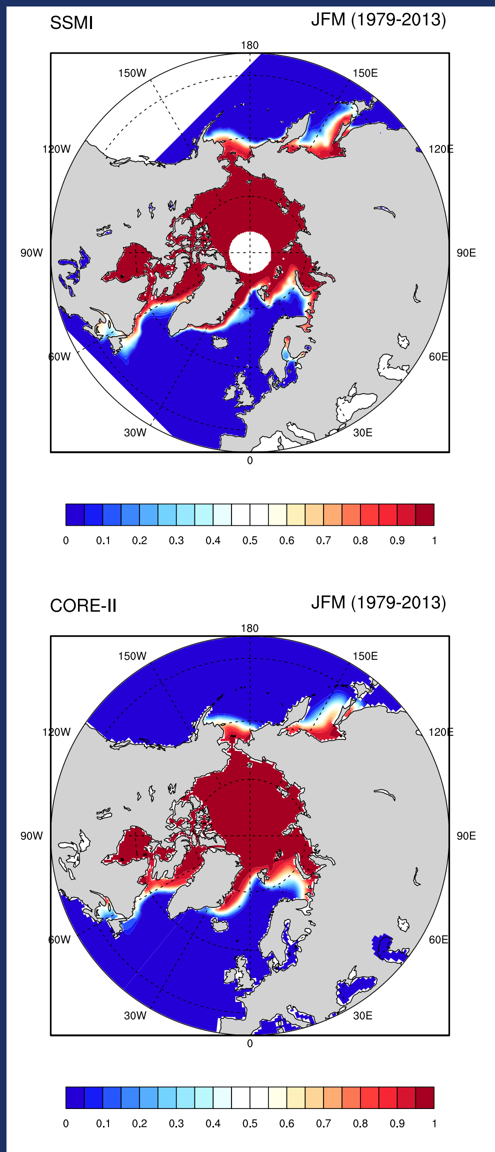
- **Changes in surface formation of NADW linked to winter NAO are reflected in decadal density anomalies in the Labrador Sea (in OBS and CORE). These ρ' are crucial aspects of DP initial conditions (but are not well-predicted).**
- **However, the DP simulations show excellent skill at predicting the propagation of ρ' into the Grand Banks region.**
- **This explains the high skill at predicting decadal modulations in the strength of the buoyancy-driven gyre with associated decadal heat transport changes across 50°N…**
- **Future SPG cooling linked to cumulative deficit of NADW since ~1996 (Robson et al. 2014; Hermanson et al. 2014; McCarthy et al. 2015; Yeager et al. 2015)**

Yeager and Robson, 2017: Recent Progress in Understanding and Predicting Atlantic Decadal Climate Variability, *Curr Clim Change Rep*, doi: 10.1007/s40641-017-0064-z.

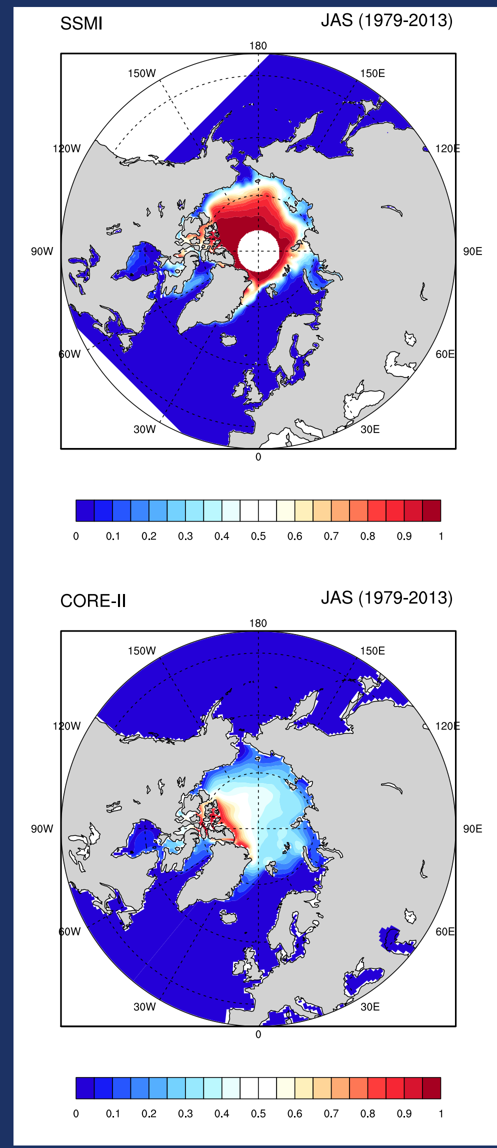
Extra Slides

CORE-forced POP-CICE (Mean State)

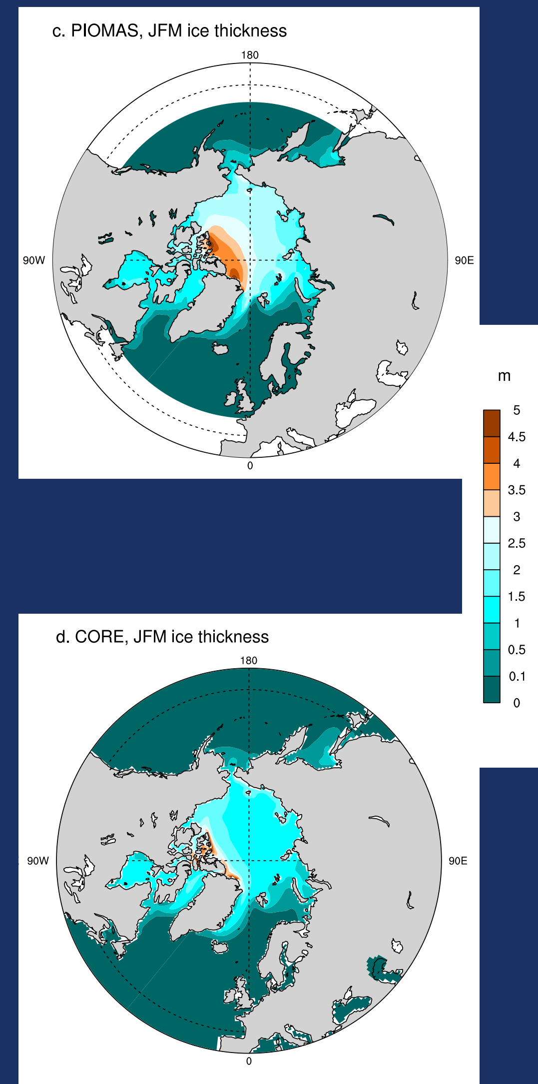
JFM sea ice fraction:



JAS sea ice fraction:

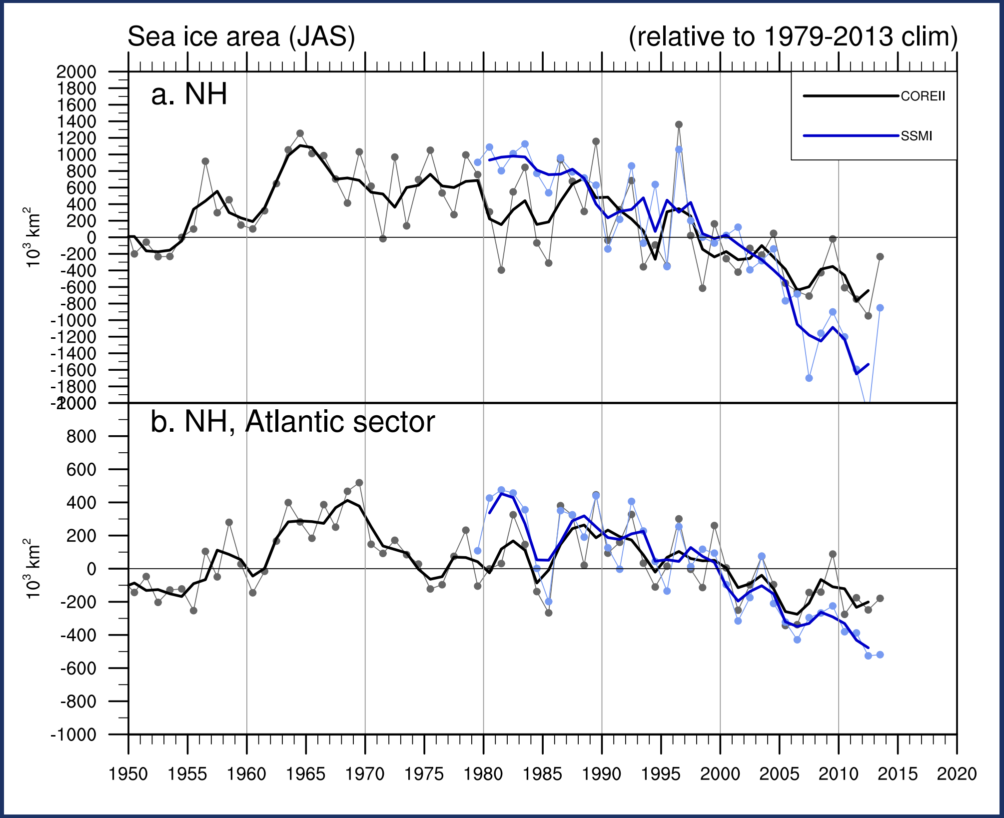


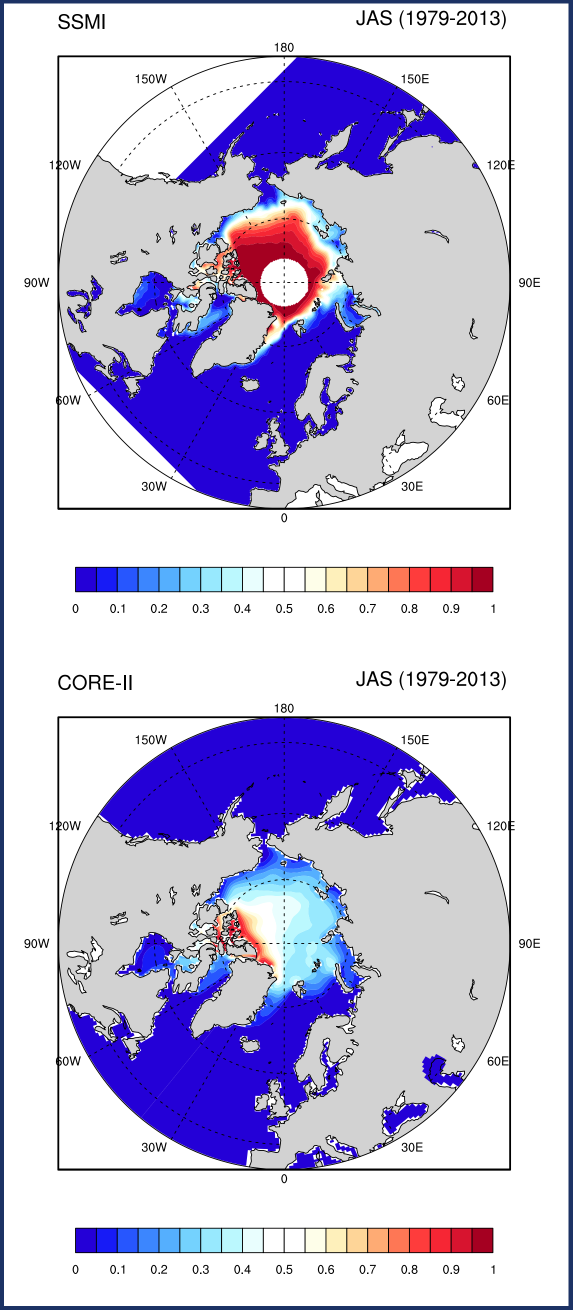
JFM sea ice thickness:



Extra Slides

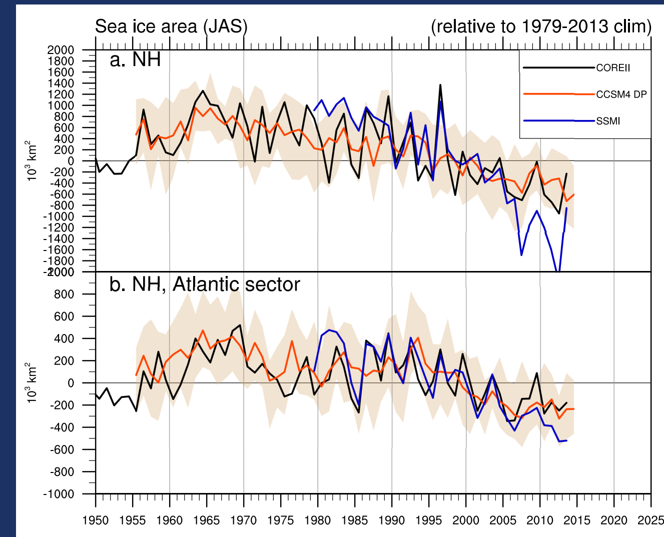
Summer NH sea ice extent
40°N-82°N :



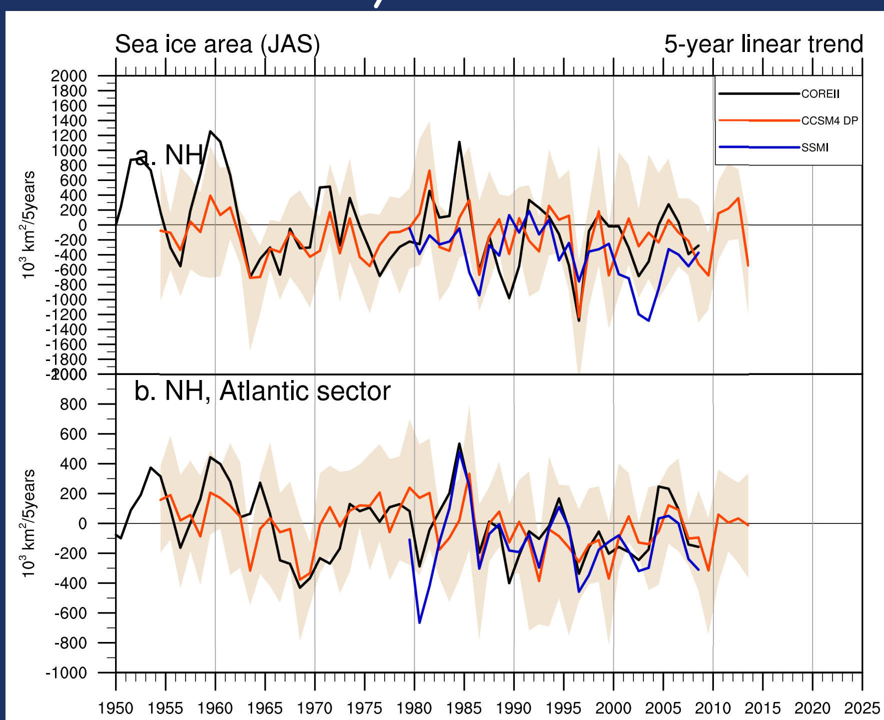


Extra Slides

Predicting trends in summer SIE



5-yr trend



10-yr trend