

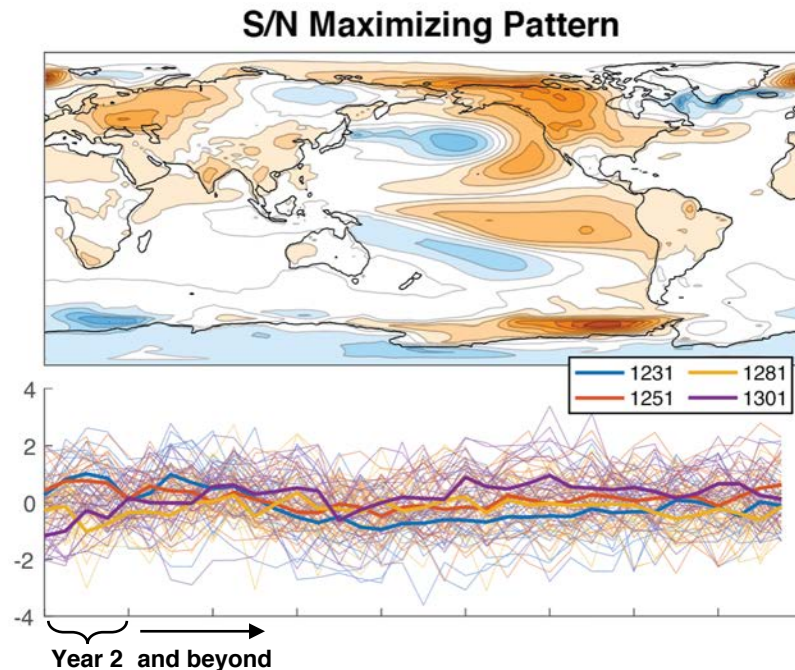
Insights into multi-year and multi-decadal predictability from ocean initial conditions in the CESM2 Large Ensemble

Robert Jnglin Wills

University of Washington, NCAR

Coauthors: Clara Deser, Who Kim, Isla Simpson, Steve Yeager, and Gokhan Danabasoglu (all NCAR)

US CLIVAR Workshop on Societally Relevant Multi-Year Climate Predictions



CESM2 Initialization Strategy

MACROs
(20 members)

Different climate states, 10 years apart
between years 1000 and 1200

MICRO 1231
(20 members)

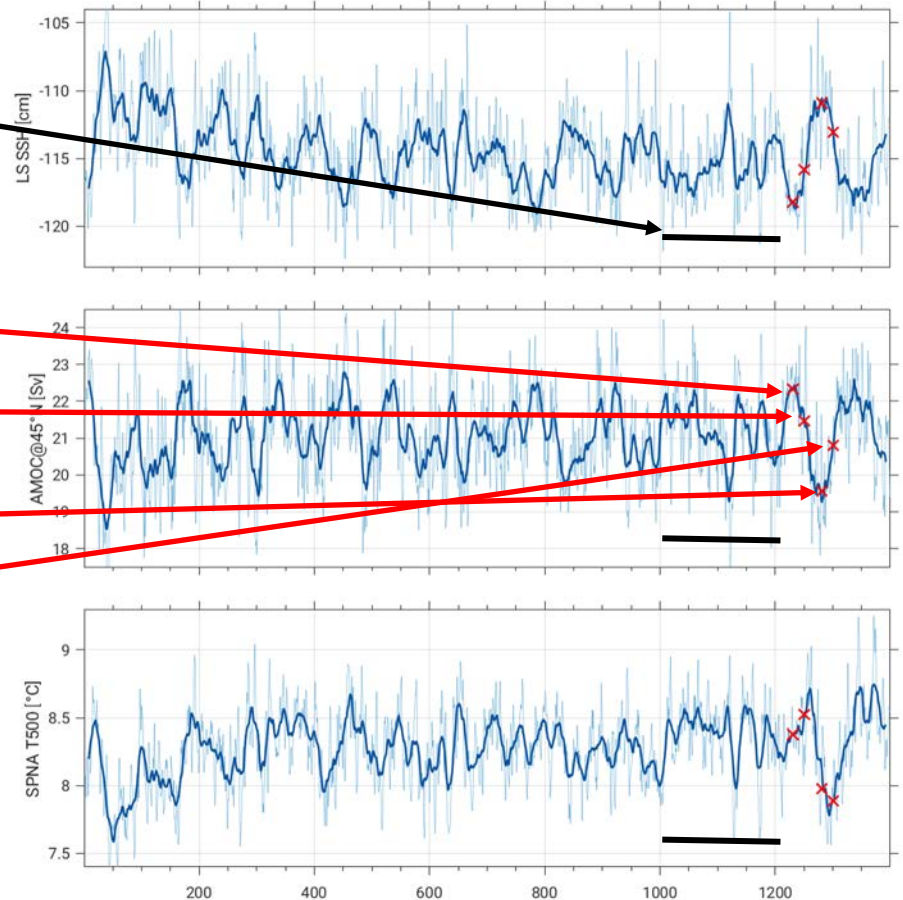
MICRO 1251
(20 members)

MICRO 1281
(20 members)

MICRO 1301
(20 members)

4 sets of 20 members, initialized from 4 different climate states
(years 1231, 1351, 1281, 1301).

The 20 members differ by “pertlim”, initial perturbation of
order 10^{-14} to the air temperature field



Research Questions & Objectives

Multi-decadal timescales:

- How long into a climate model simulation does the choice of initial ocean state matter?
- What processes lead to dependence on initial ocean state decades or centuries into a simulation?

Multi-year timescales:

- What processes lead to multi-year predictability in CESM2 simulations with different initial ocean states?
- Demonstration of the utility of signal-to-noise maximizing pattern filtering for initial condition predictability

Variance Decomposition and Predictable Fraction

The total variance in CESM2-LE can be split up into variance due to *atmospheric initial conditions* (variance within the micro ensembles) and variance due to *ocean initial conditions* (variance between the micro ensemble means)

$$\sigma_{\text{total}}^2 = \sigma_{\text{ocean}}^2 + \sigma_{\text{atmos}}^2$$

The fraction of variance predictable from ocean initial conditions is given by:

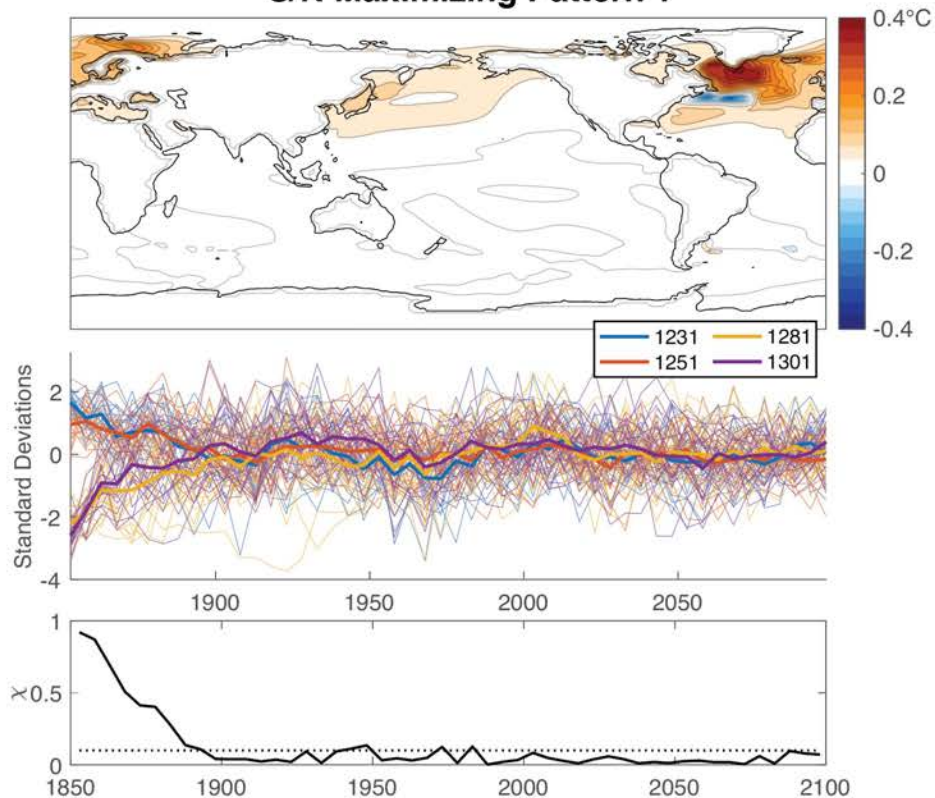
$$\chi = \frac{\sigma_{\text{ocean}}^2}{\sigma_{\text{total}}^2}$$

Signal-to-Noise Maximizing Pattern Analysis

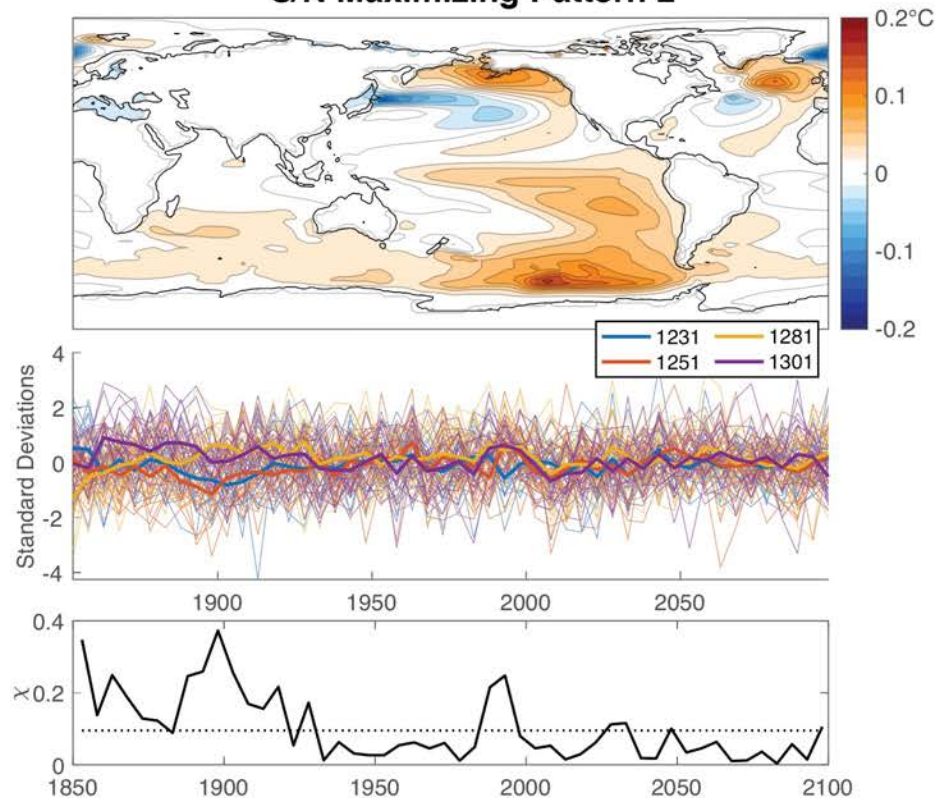
- **Signal-to-noise maximizing pattern analysis** is a method to compute the patterns (linear combinations of EOFs) that maximize a signal-to-noise ratio (Schneider & Griffies 1999; Ting et al. 2009; Wills et al. 2020), e.g., with signal computed from an ensemble average
- **Signal-to-noise maximizing pattern filtering** combines the significant signal-to-noise maximizing patterns into a new dataset, filtering out other patterns of variability. Wills et al. 2020 showed that this can identify forced responses with up to 10 times fewer ensemble members than an ensemble mean.
- Here, we define:
 - **Signal:** differences between MICRO ensemble means
 - **Noise:** differences between members of each MICRO ensemble

Initial Condition Predictability on Multi-Decadal Timescales

S/N Maximizing Pattern 1



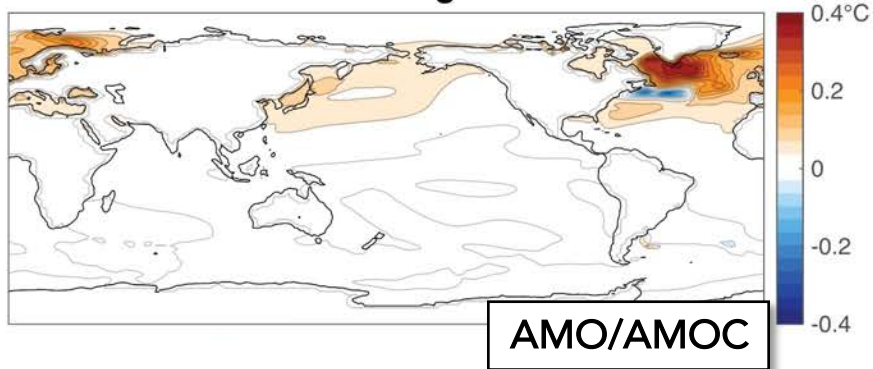
S/N Maximizing Pattern 2



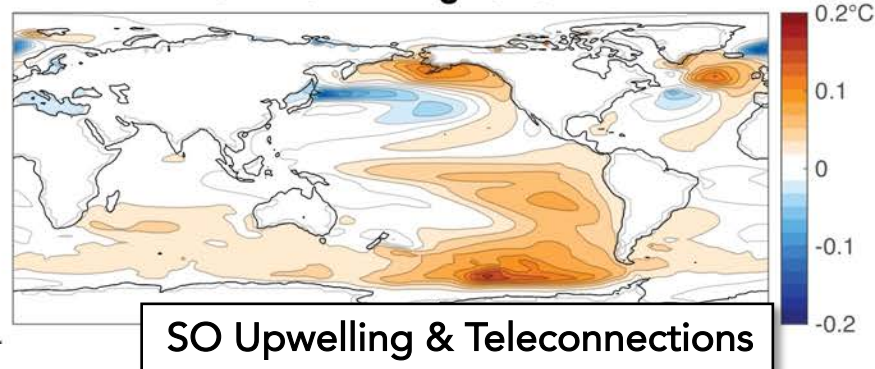
Analysis of 5-yr-mean SST anomalies in CESM2-LE

Initial Condition Predictability on Multi-Decadal Timescales

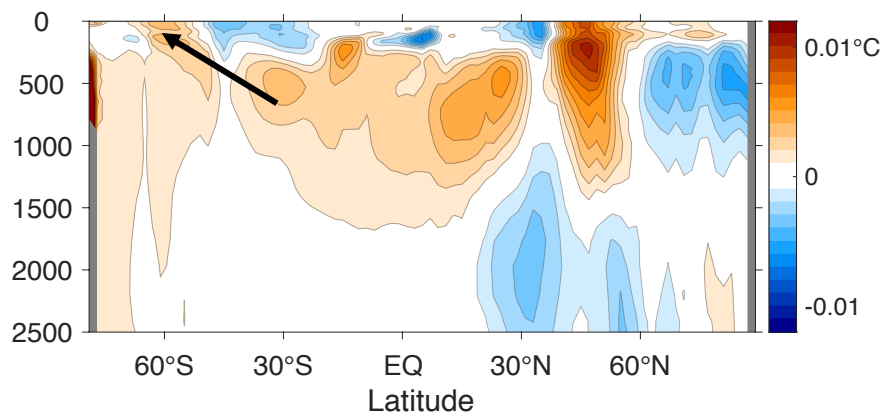
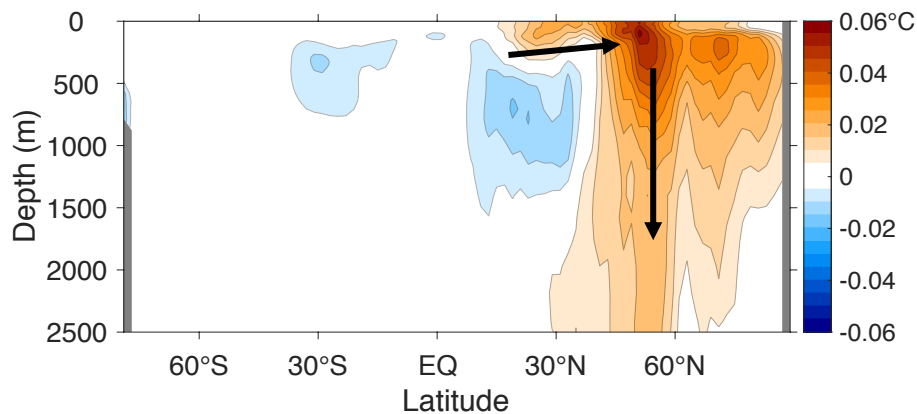
S/N Maximizing Pattern 1



S/N Maximizing Pattern 2

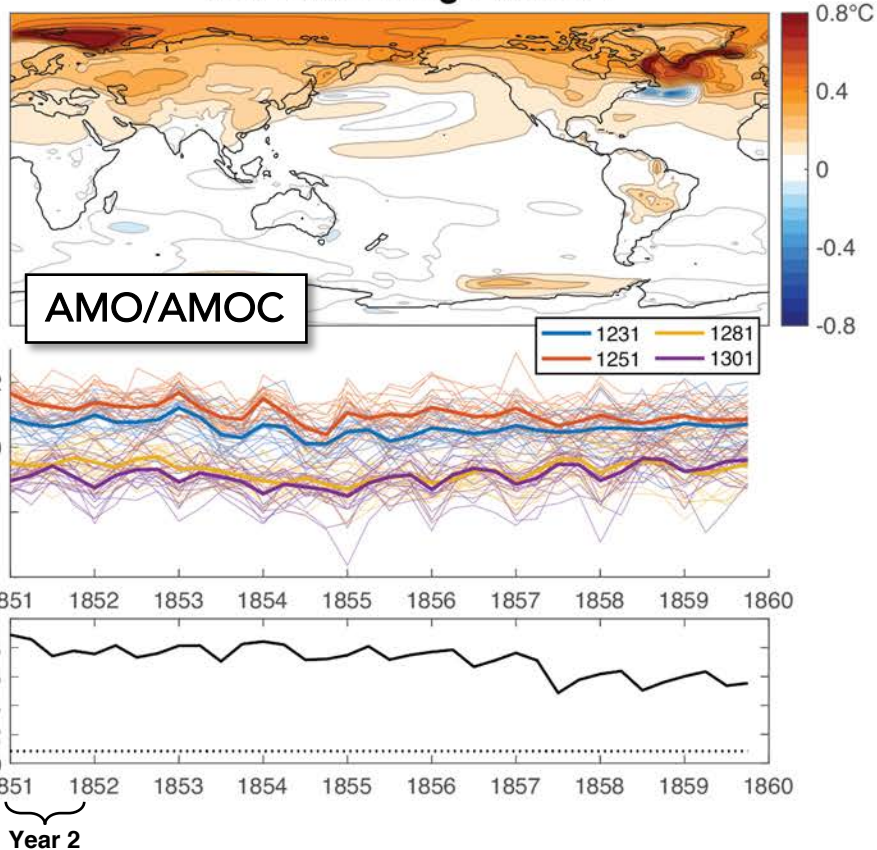


Associated zonal-mean ocean temperature anomaly

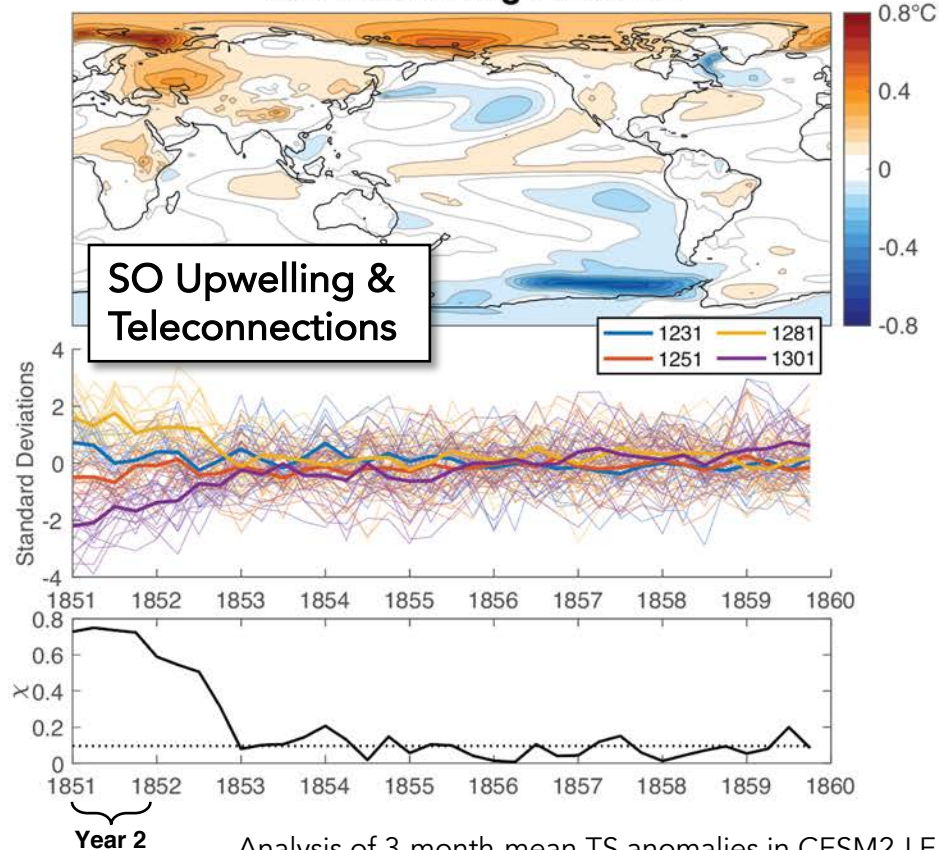


Initial Condition Predictability on Multi-Year Timescales

S/N Maximizing Pattern 1



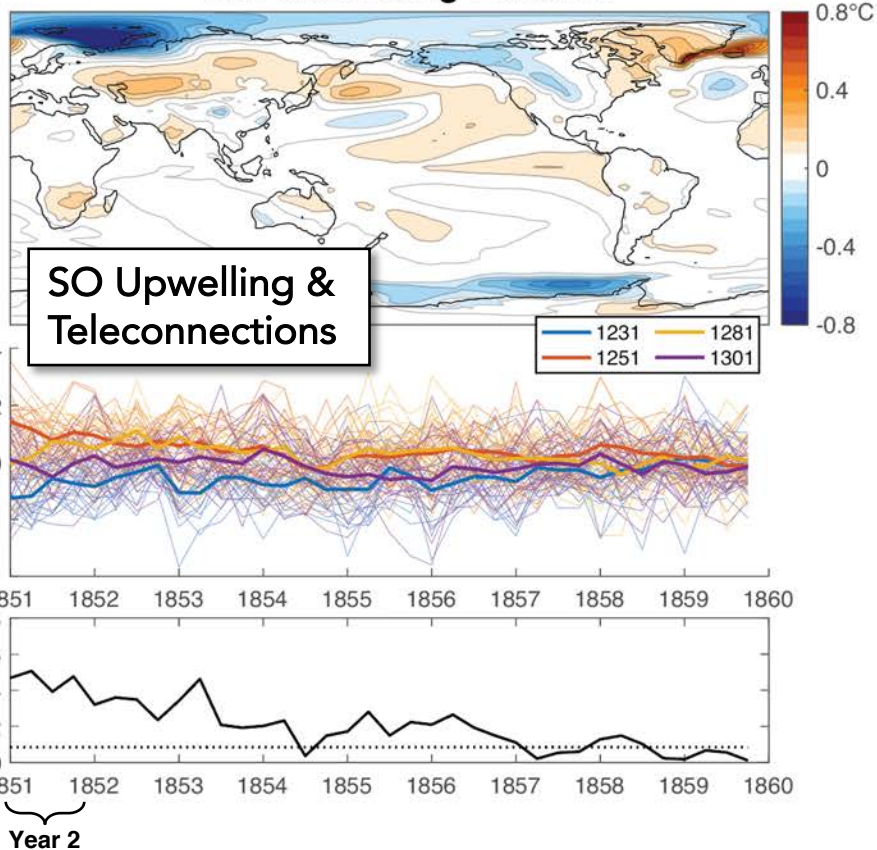
S/N Maximizing Pattern 2



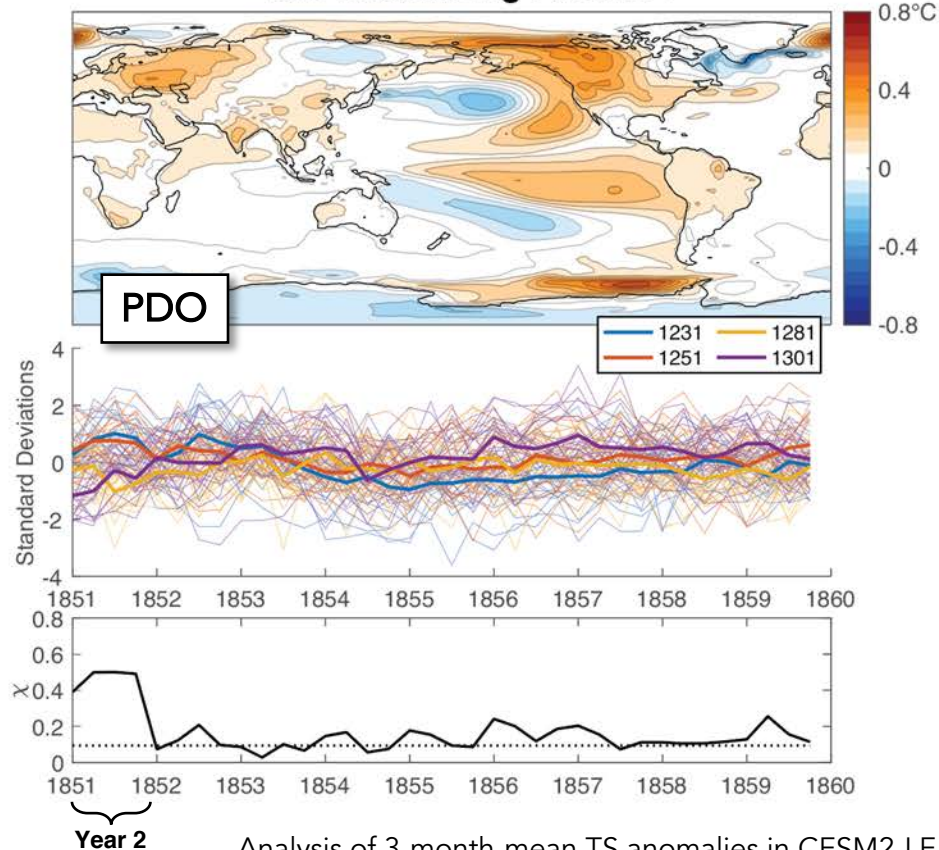
Analysis of 3-month-mean TS anomalies in CESM2-LE

Initial Condition Predictability on Multi-Year Timescales

S/N Maximizing Pattern 3



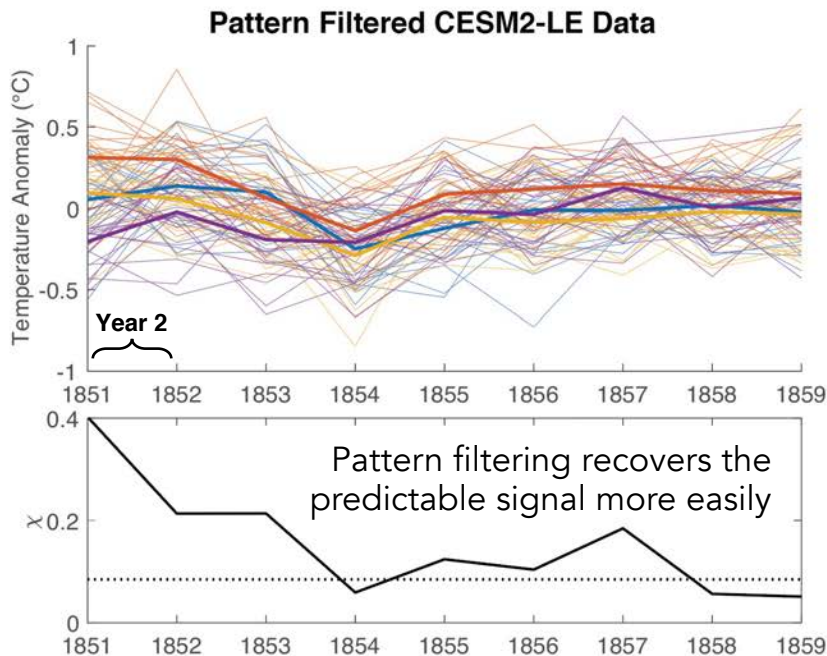
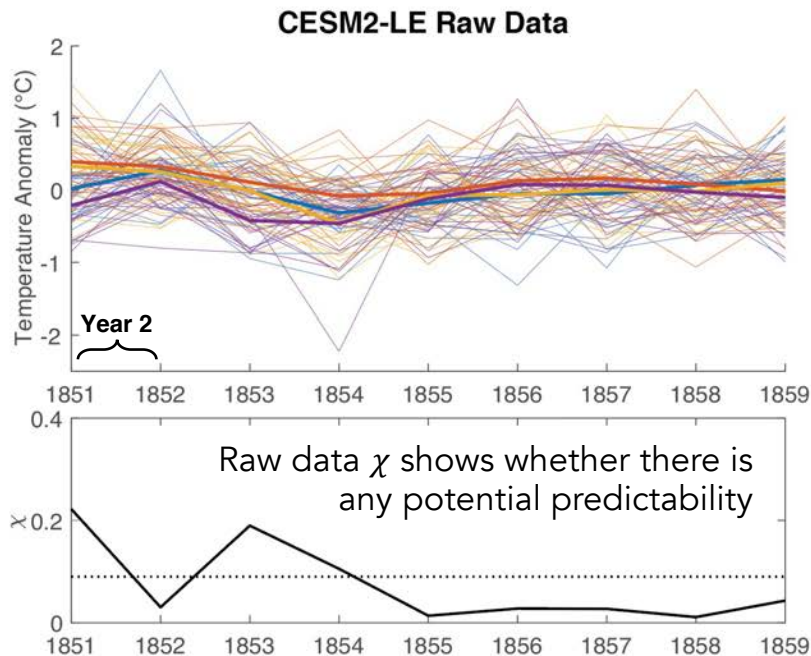
S/N Maximizing Pattern 4



Analysis of 3-month-mean TS anomalies in CESM2-LE

Utility of Signal-to-Noise Maximizing Pattern Filtering for Initial Condition Predictability

US-SW JJA Temperature Anomalies (30-40°N, 105-125°W)

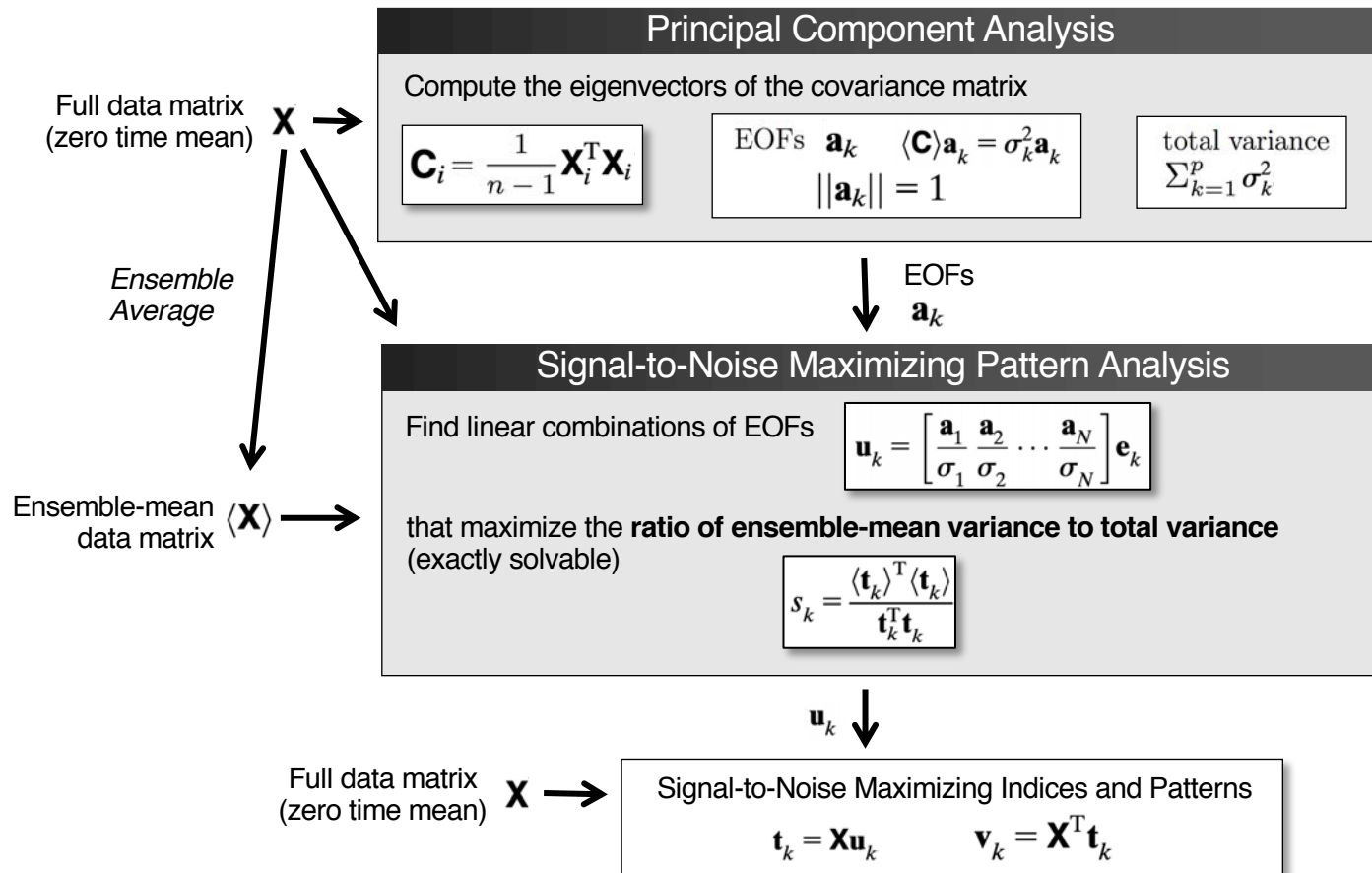


Proposed strategy: use pattern filtering to extract predictable signal, then use an estimate of the interannual variance to determine whether prediction is detectable

Summary & Conclusions

- The choice of ocean initial conditions impacts surface conditions for at least 50 years and up to 150 years into a coupled climate model simulation
- The main processes leading to multi-decadal initial condition predictability are AMO/AMOC and Southern Ocean upwelling
- The AMO is also the largest source of initial-condition predictability at multi-year timescales
- Various 'flavors' of PDO and Southern Ocean upwelling also lead to multi-year predictability
- Signal-to-noise maximizing filtering can isolate a predictable signal with fewer ensemble members than an ensemble mean

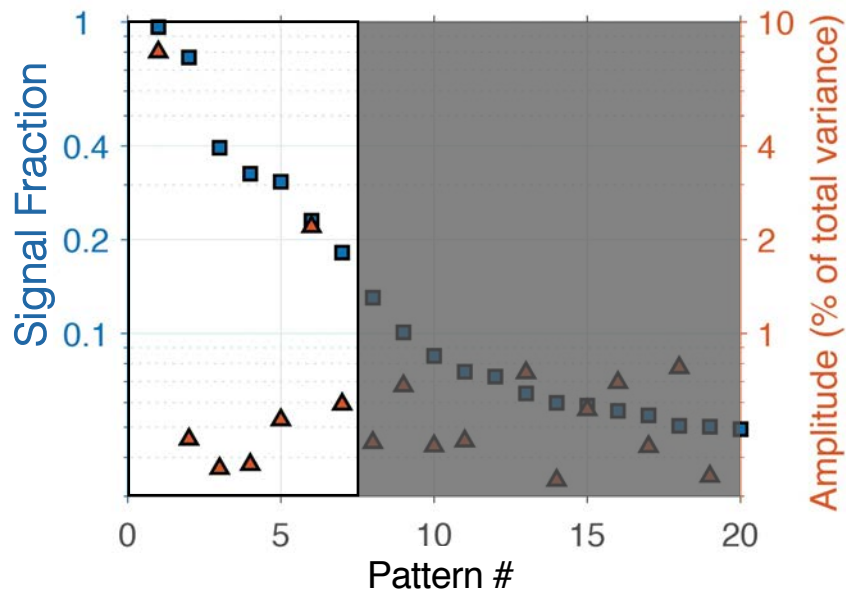
Methods: Signal-to-Noise Maximizing Patterns



Methods: S2N Maximizing Pattern Filtering

Eigenvalue of
S/N Pattern
Analysis

Eigenvalue of
EOF Analysis



- Use any of a variety of methods (e.g., bootstrapping) to determine number of significant S/N maximizing patterns
- **Pattern Filtering:** Keep only variability associated with significant S/N maximizing patterns; combine patterns and timeseries to create spatiotemporal data

Methods: Data Preprocessing

- We use data from four 20-member micro ensembles initialized from years 1231, 1251, 1281, and 1301 of the piControl simulation
- All data are coarsened to an a 144x96 analysis grid (nominally 2°)
- The (seasonal) climatology over the full analysis period is removed
- Data are averaged to 5-year or 3-month temporal resolution