ENSO forecast skill in a changing climate

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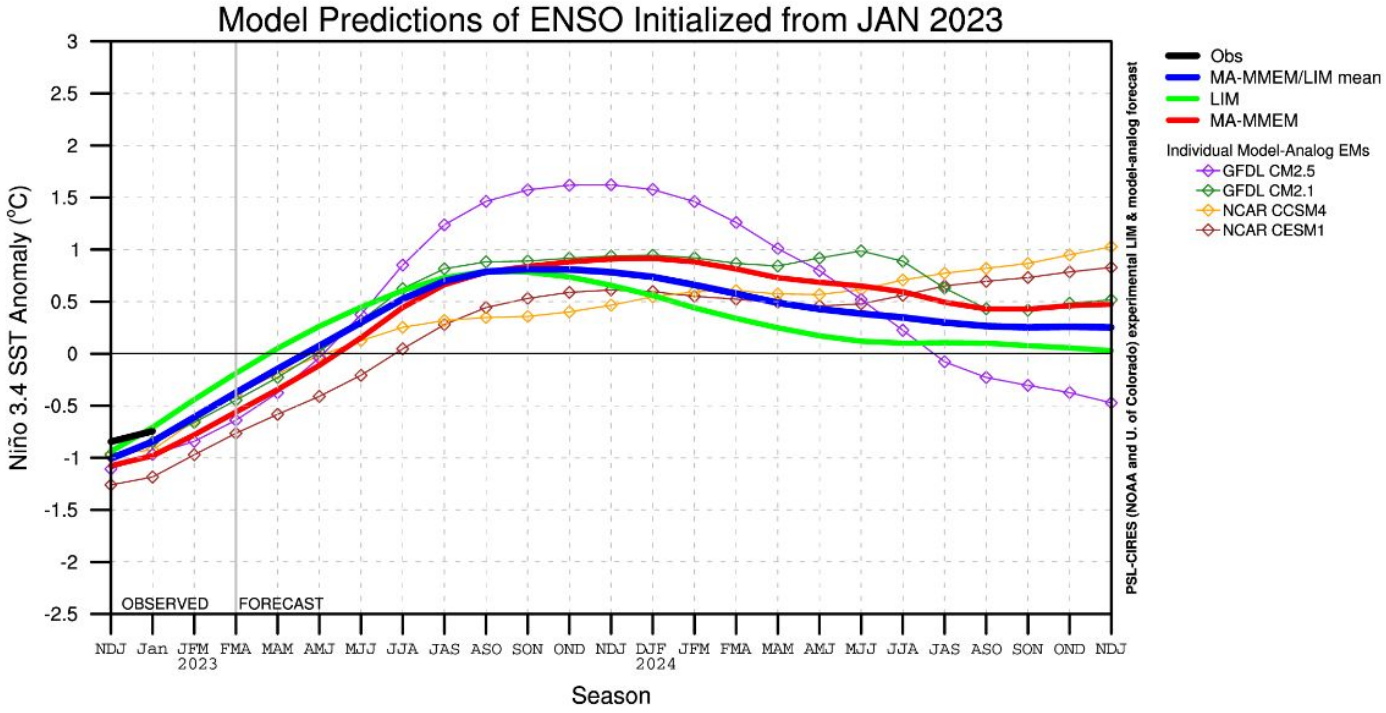
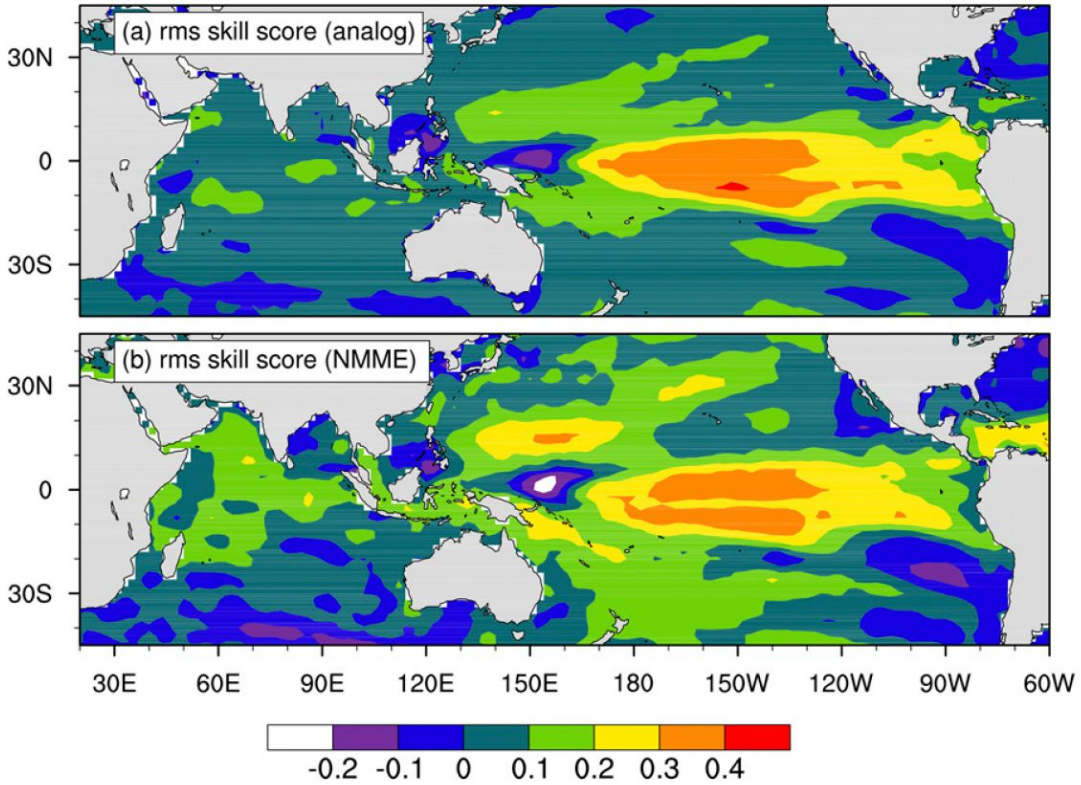
Motivation: Multi-decadal variation of ENSO forecast skill



Screenshot: The real-time seasonal ENSO predictions made by **model-analog technique**.

https://www.psl.noaa.gov/forecasts/seasonal/

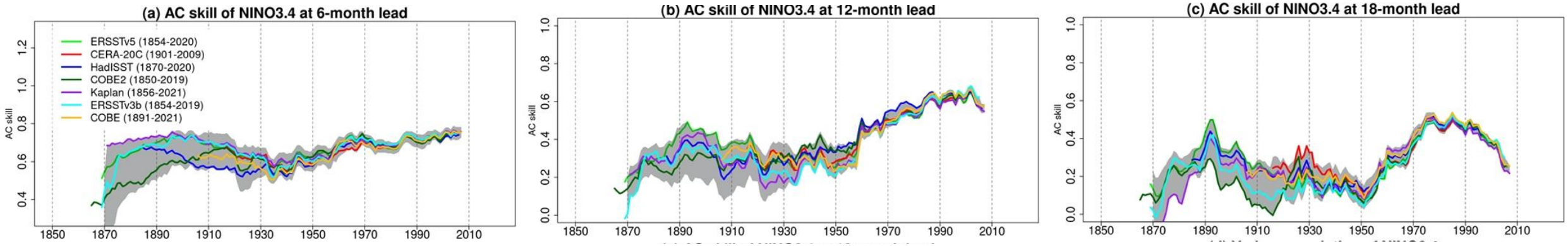
Root mean square skill score of SST at 6-month lead



Ding et al. (2018; J. Clim.)

Figure: Model-analog and NMME hindcast skills of monthly SSTa at 6-month forecast lead for the period of 1982-2015.

ENSO forecast skill underwent multi-decadal variations with the minimum skill in the middle of 20th century.



(Lou, Newman, and Hoell. submitted)

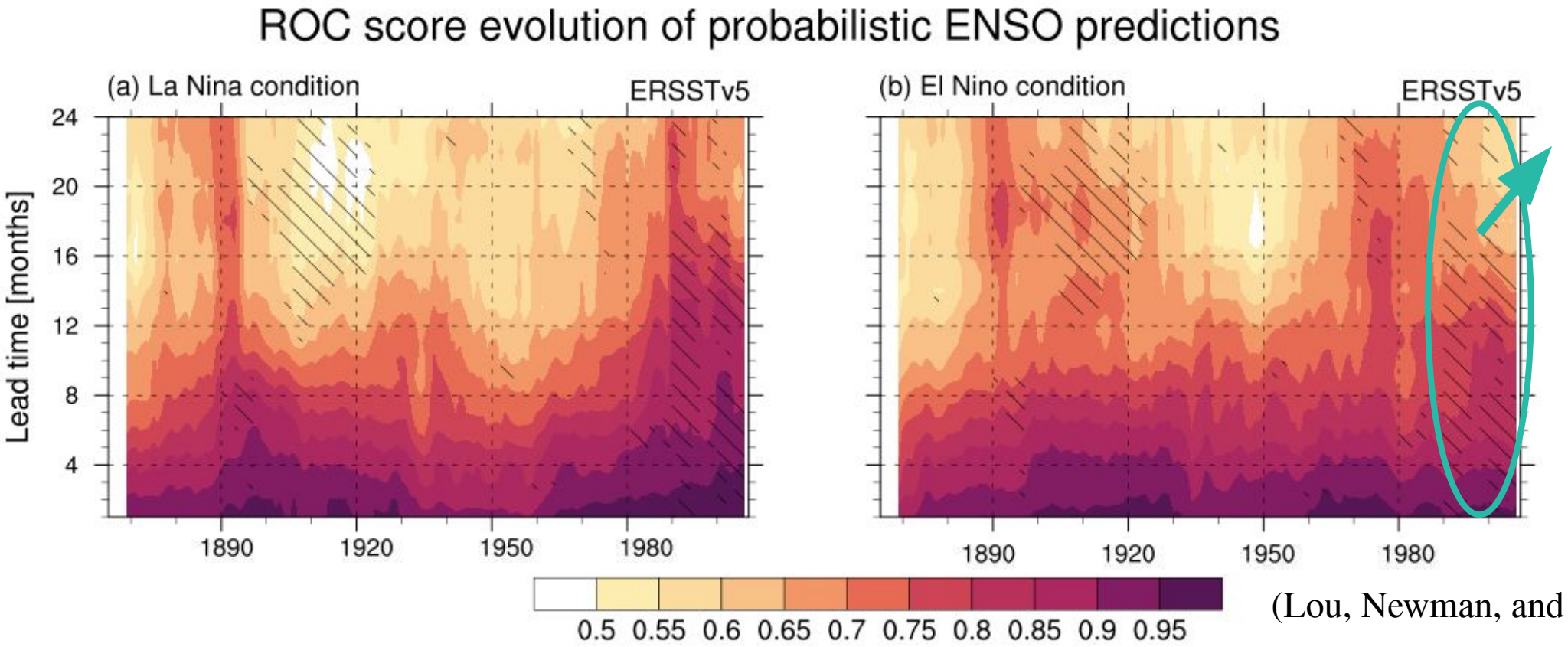
Figure: Cross-verification of the ensemble-mean anomaly correlation (AC) skill evolution of NINO3.4 predictions over the 30-year sliding hindcast windows for NINO3.4 time series.

Probabilistic ENSO forecast skill underwent multi-decadal variations with the minimum skill in the middle of 20th century.

ROC score: hit rate vs. false alarm rate

ROC score = 1 Perfect score

ROC score < 0.5 No skill



La Niña being more predictable than El Niño is recent. Given the reverse earlier in the record it may be by chance.

(Lou, Newman, and Hoell. submitted)

Figure: Predictive relative operating characteristic (ROC) area evolution for (a) La Niña condition and (b) El Niño condition based on NINO3.4 time series over the 30-year moving hindcast windows.

ENSO forecast skill corresponds well with the variance change

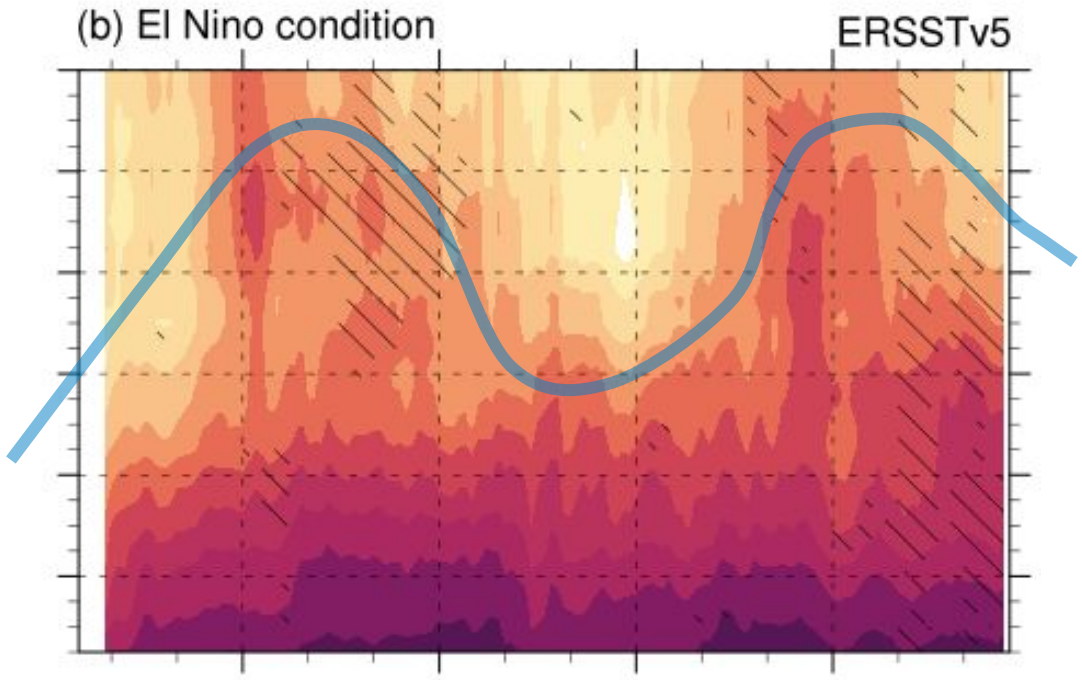


Figure: same as in previous slide

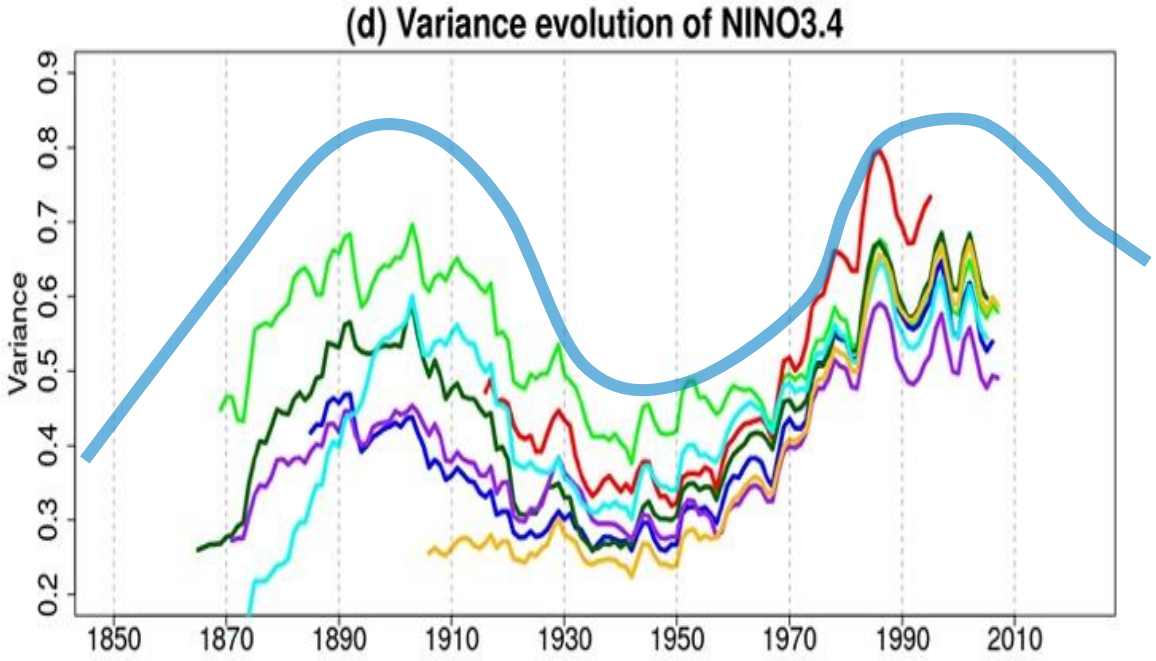


Figure: 30-yr moving variance of NINO3.4 index based on seven observations.

(Lou, Newman, and Hoell. submitted)

Question: How much can we attribute the past multi-decadal variation of ENSO forecast skill to climate change vs. internal variability?

Experiment design

Experiment 1: Library: CESM2 **piControl** simulation (1200 year)

Experiment 2: Library: CESM2 large ensemble (**CESM2LENS**; 100 ensemble members)

12-year moving window [12 (year) *100 (ensemble)=1200 samples]
e.g., verification year: 1972, library year: 1960-1971

Experiment 3: **Perfect model** experiment
CESM2LENS
10-year chunk of period (1871-1880; 1881-1890; … 2001-2010; 2011-2020)

CESM2 piControl vs. historical large ensemble

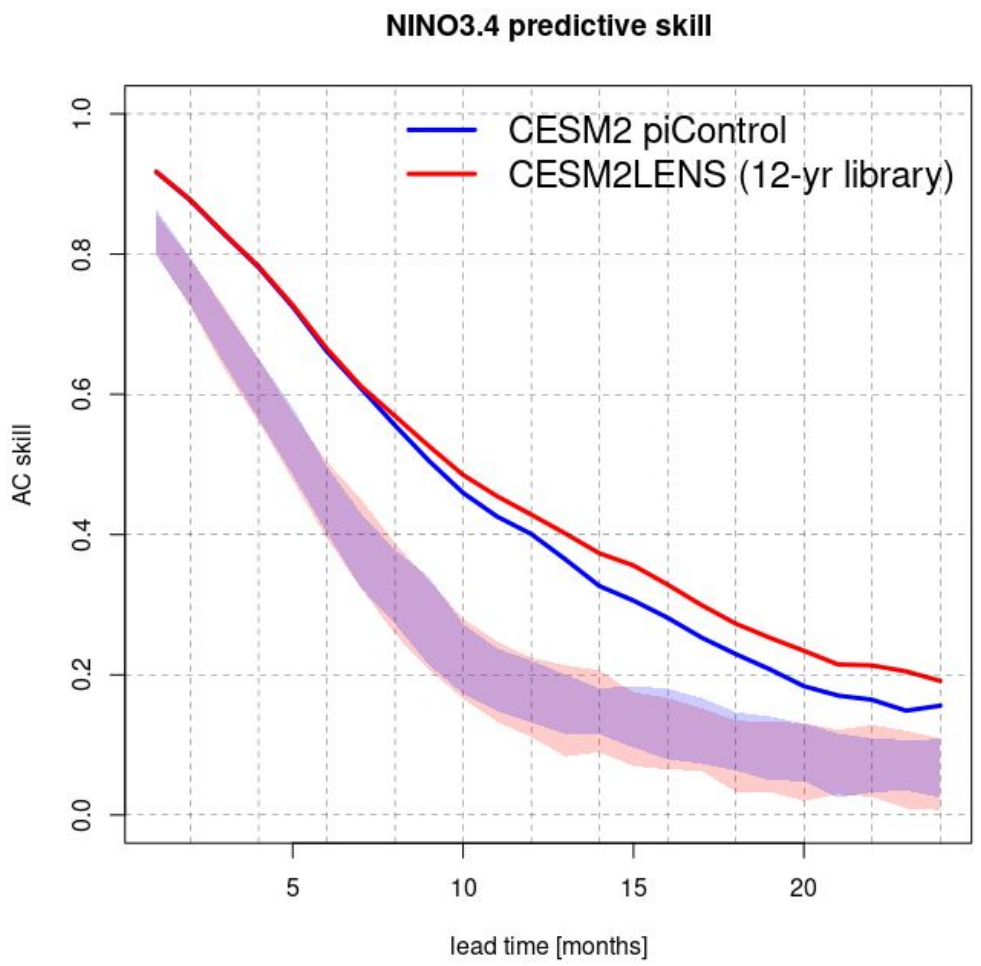


Figure: AC skill of NINO3.4 for the period of 1871-2020.

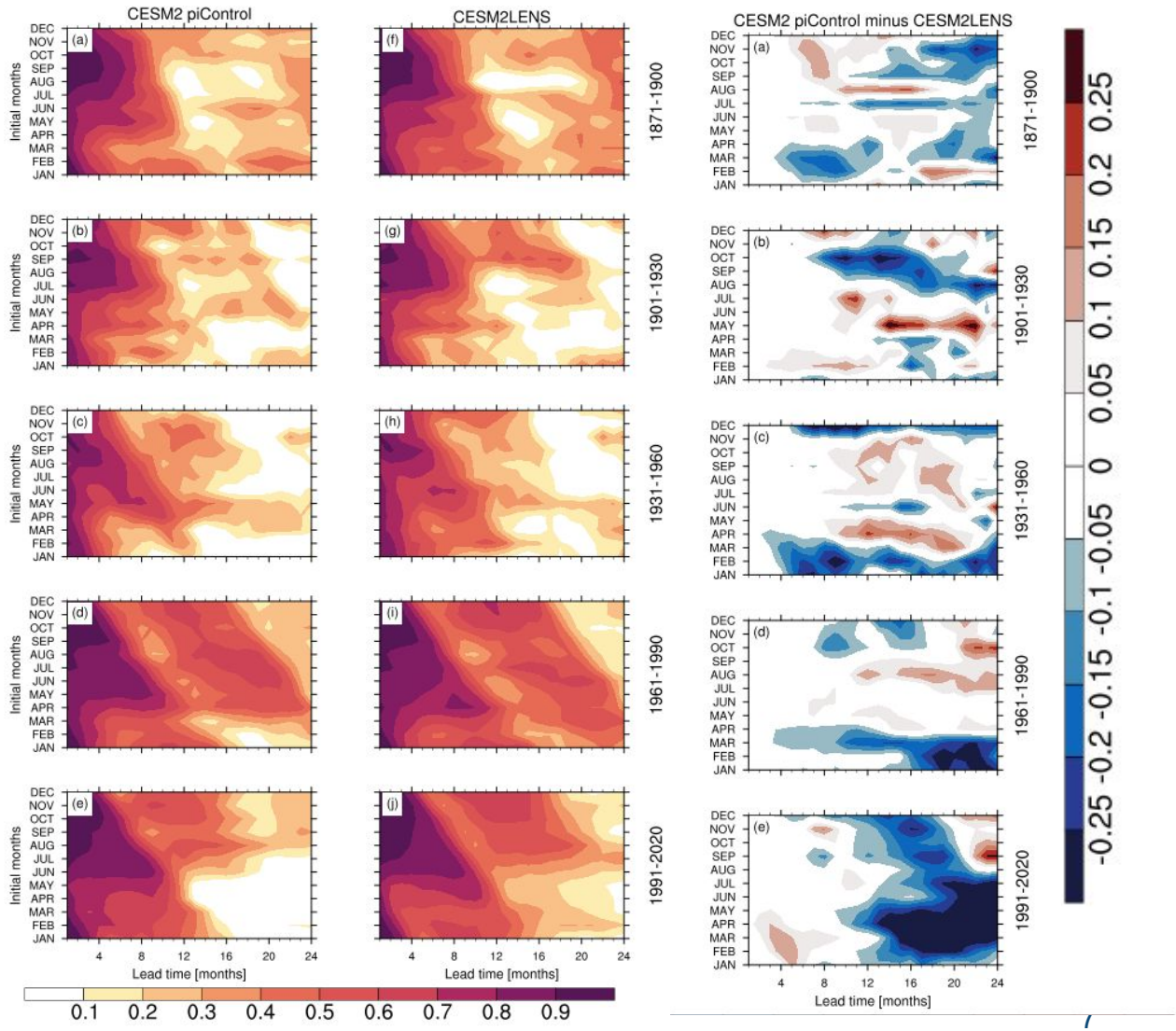


Figure: Seasonality of NINO3.4 forecast skill.

Perfect model experiment – CESM2LENS

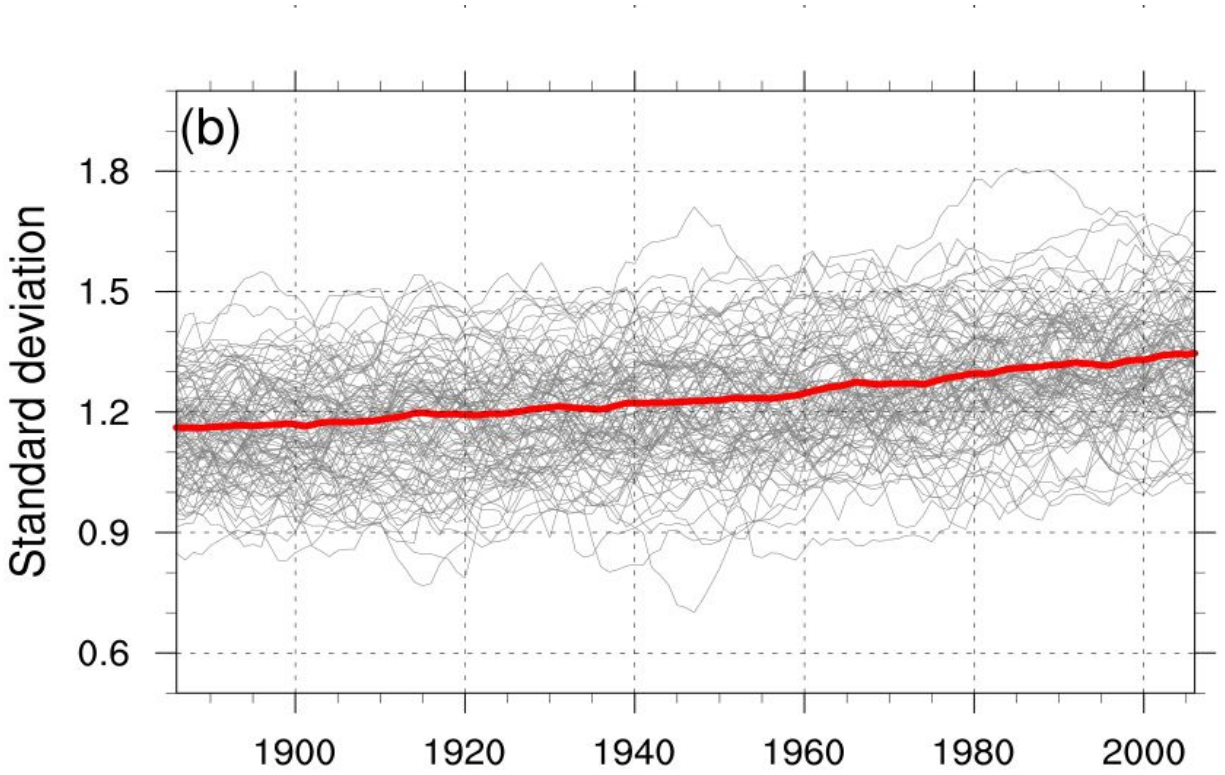


Figure: 30-yr moving standard deviation of NINO3.4 in CESM2LENS.

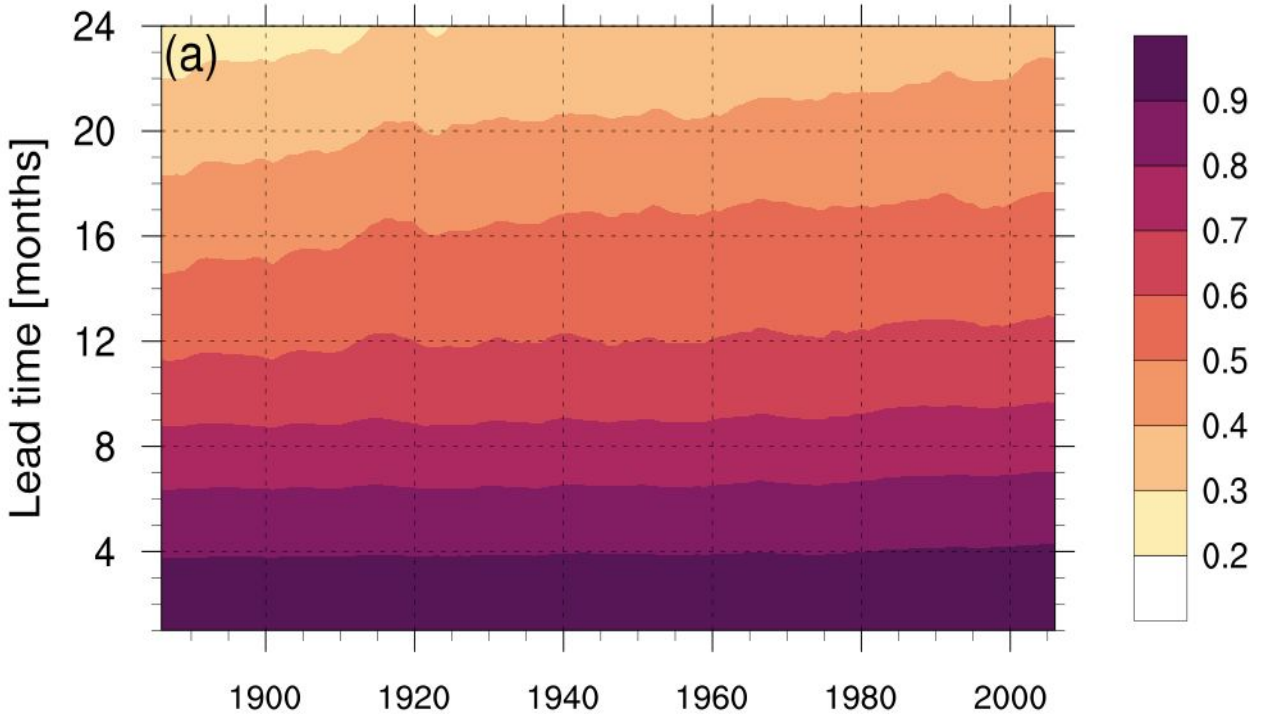
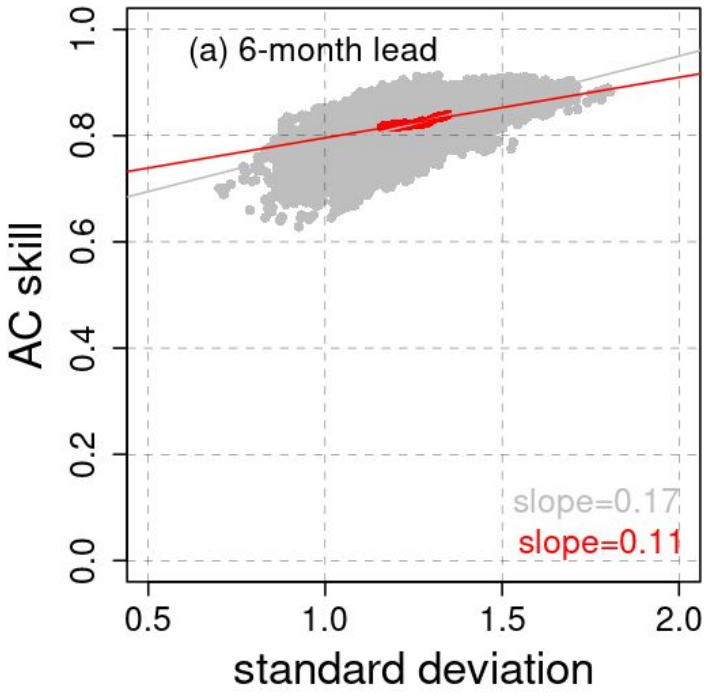
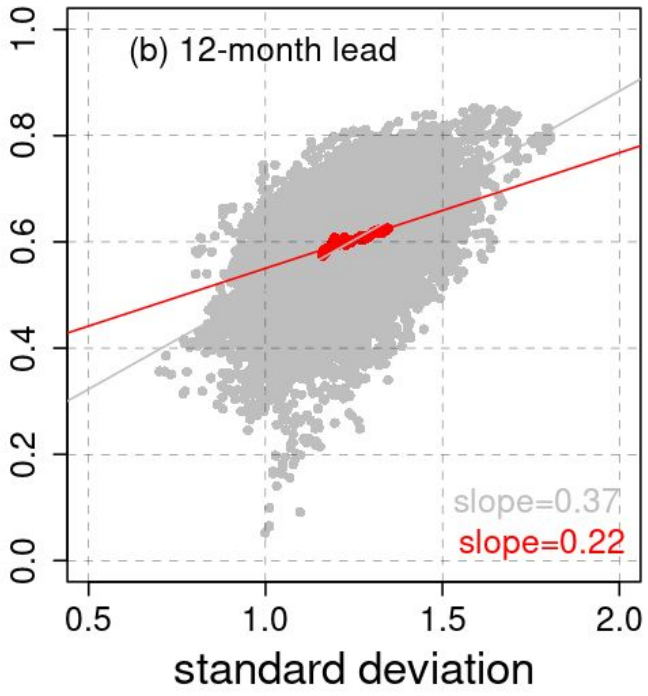
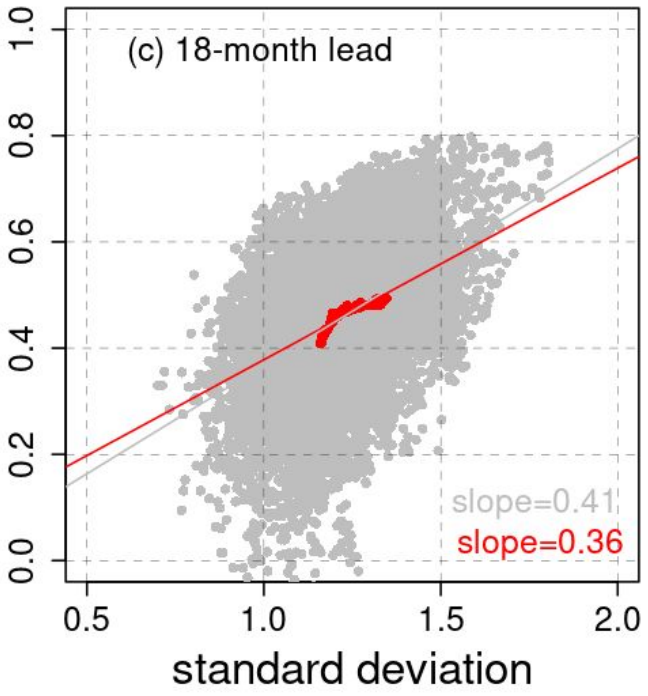


Figure: Perfect-model AC skill of NINO3.4 predictions over the 30-yr moving hindcast windows.

Relationship between ENSO forecast skill and its variance







Perfect model experiment – CESM2LENS

Since each ensemble member simulates ENSO variations differently, we selected a few that correctly reproduce the minimum variance observed in the mid-20th century.

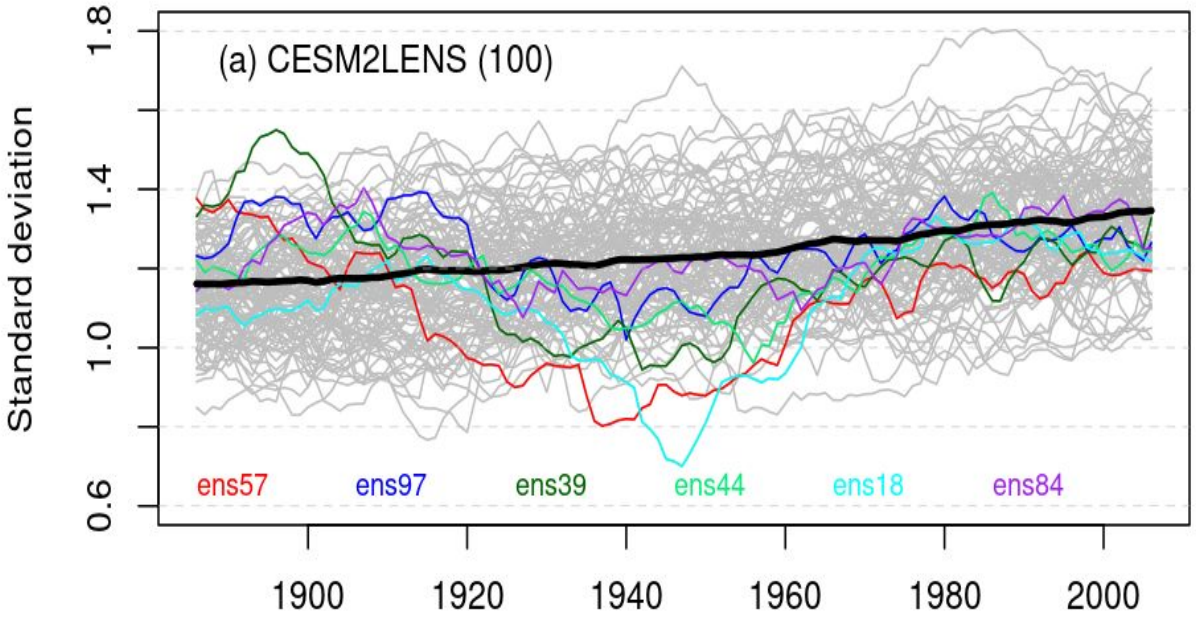


Figure: 30-yr moving standard deviation of NINO3.4 in CESM2LENS.

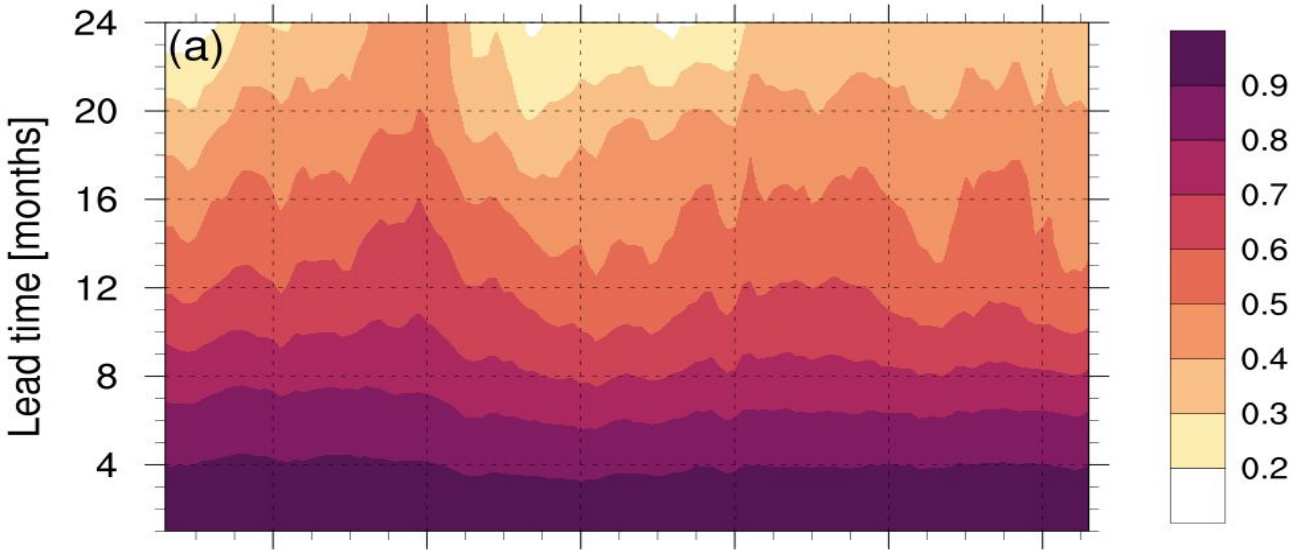


Figure: Perfect-model AC skill of NINO3.4 predictions over the 30-yr moving hindcast windows.

The ENSO forecast skill **decreases** due to the **reduction** of ENSO variance in the mid-20th century.

Summary

Conclusions:

- ENSO forecast skill underwent **multi-decadal variations** with the minimum skill in the middle of 20th century;
- La Niña predictions have been generally more skillful than El Niño, at both short and long leads **in recent decades**, but this difference may be **transient**.

Ongoing: How much can we attribute the past multi-decadal variation of ENSO forecast skill to climate change vs. internal variability?

- ENSO variability is mainly **internally forced**;
- If **externally-forced** ENSO variance increases in a changing climate, the forecast skill will increase correspondingly.

J. Lou, M. Newman, A. Hoell. Multi-decadal variation of ENSO forecast skill since the late 1800s. (submitted)
J. Lou, M. Newman, A. Hoell, A. Wittenberg. ENSO forecast skill in a changing climate. (in prep.)

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Supplement

Multi-decadal variation of ENSO forecast skill since the late 1800s using the model-analog technique

Analog: if two atmospheric states resemble each other rather closely, each of the state can be viewed as equivalent to the other state plus reasonably small perturbations (Lorenz 1969).

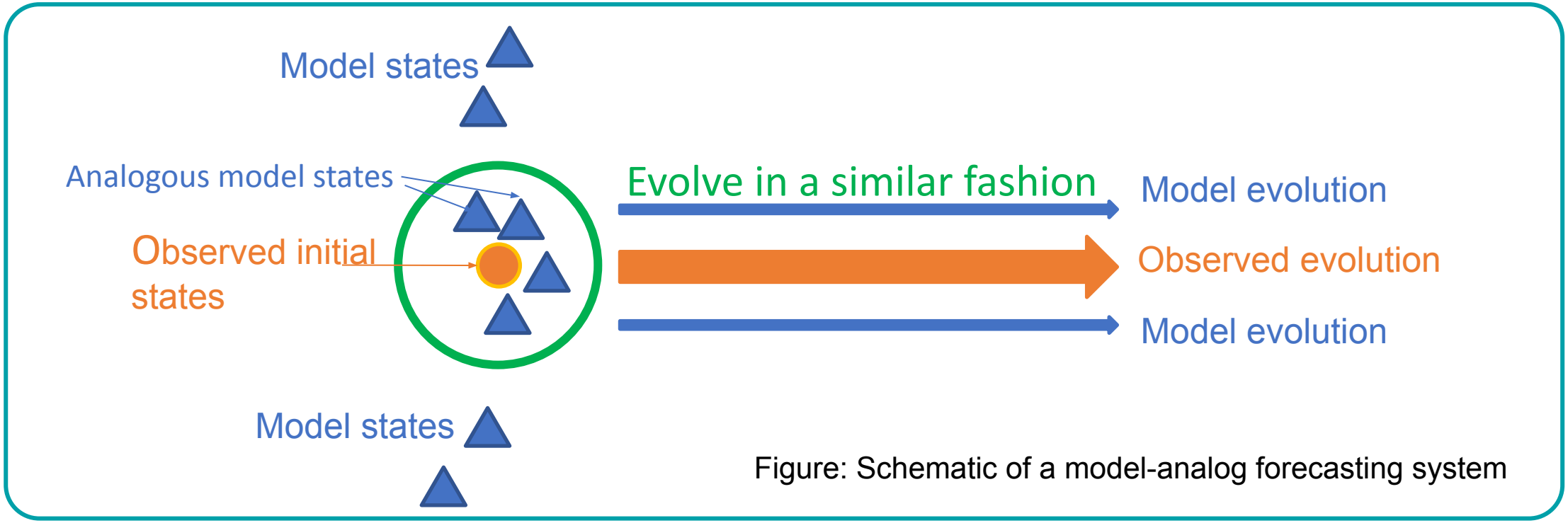


Figure: Schematic of a model-analog forecasting system

Advantages:

- **Construct model-analogs to estimate its own state (no initialization shock)**
- **Forecasts with no additional integration needed (computationally cheap)**

Model-analog skill is comparable to skill from the traditional assimilation-initialized operational model (ECMWF SEAS5) since 1900s.

CMIP6 **model-analog** forecasts

Operational model: Initialized seasonal hindcast experiments for the 20th century, produced using a version of the ECMWF's Integrated Forecasting System (IFS). [Weisheimer et al. (2022; GRL)]

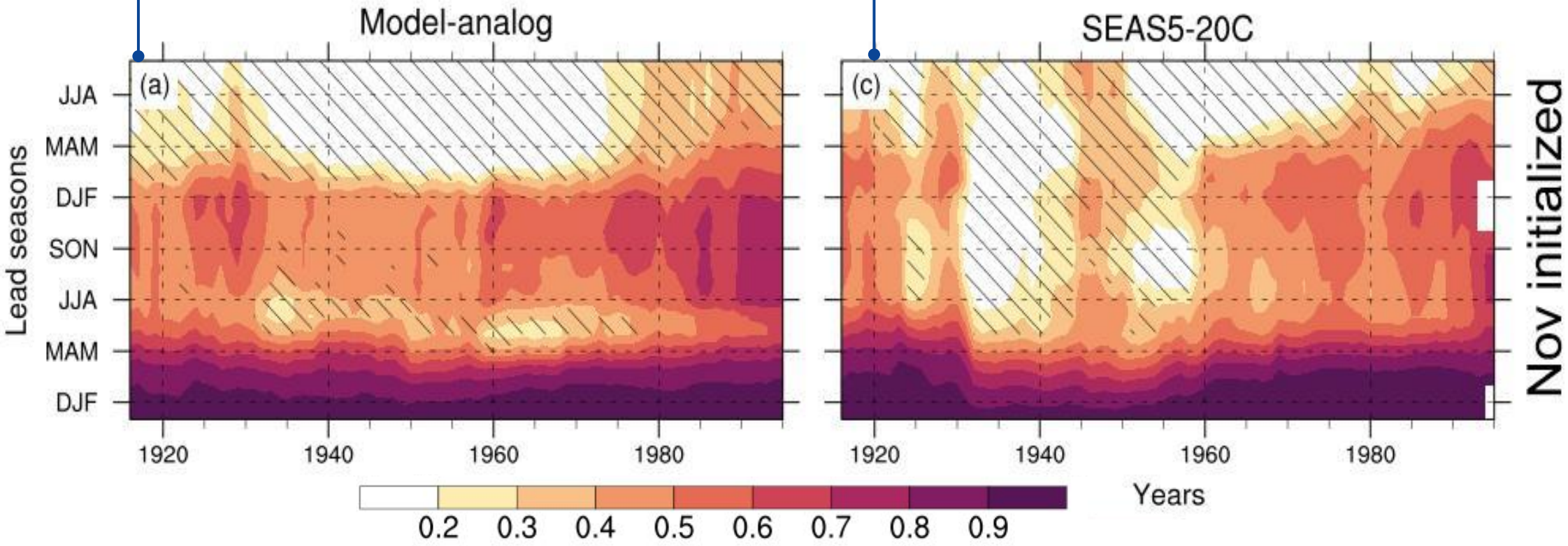
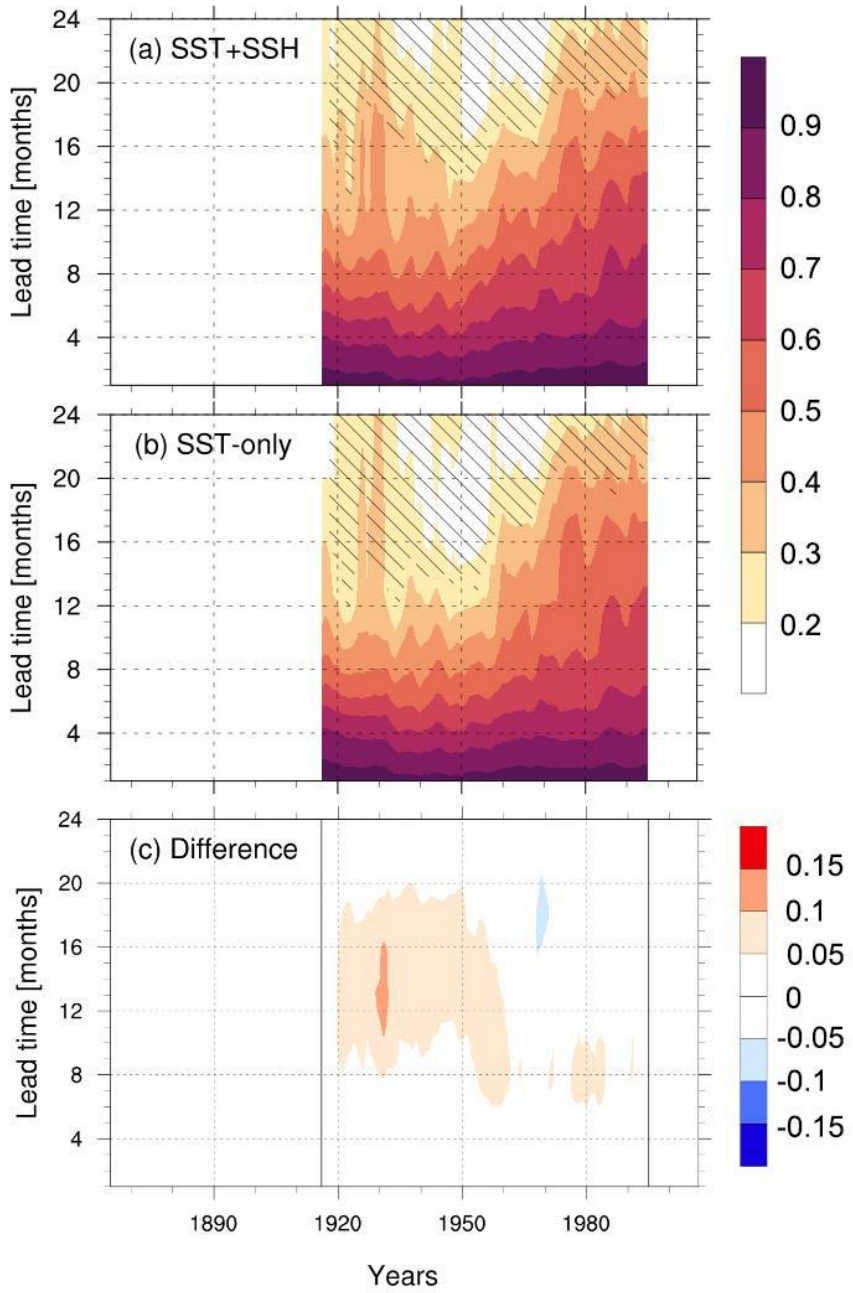
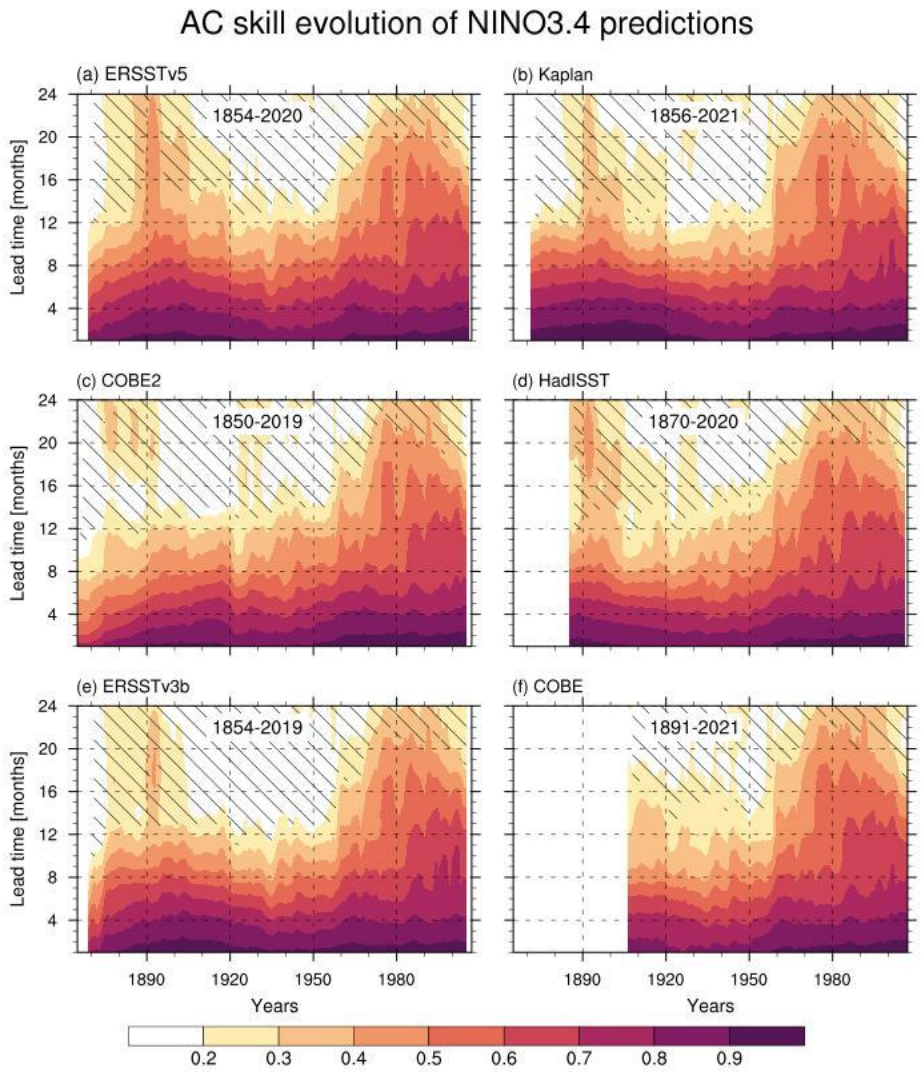


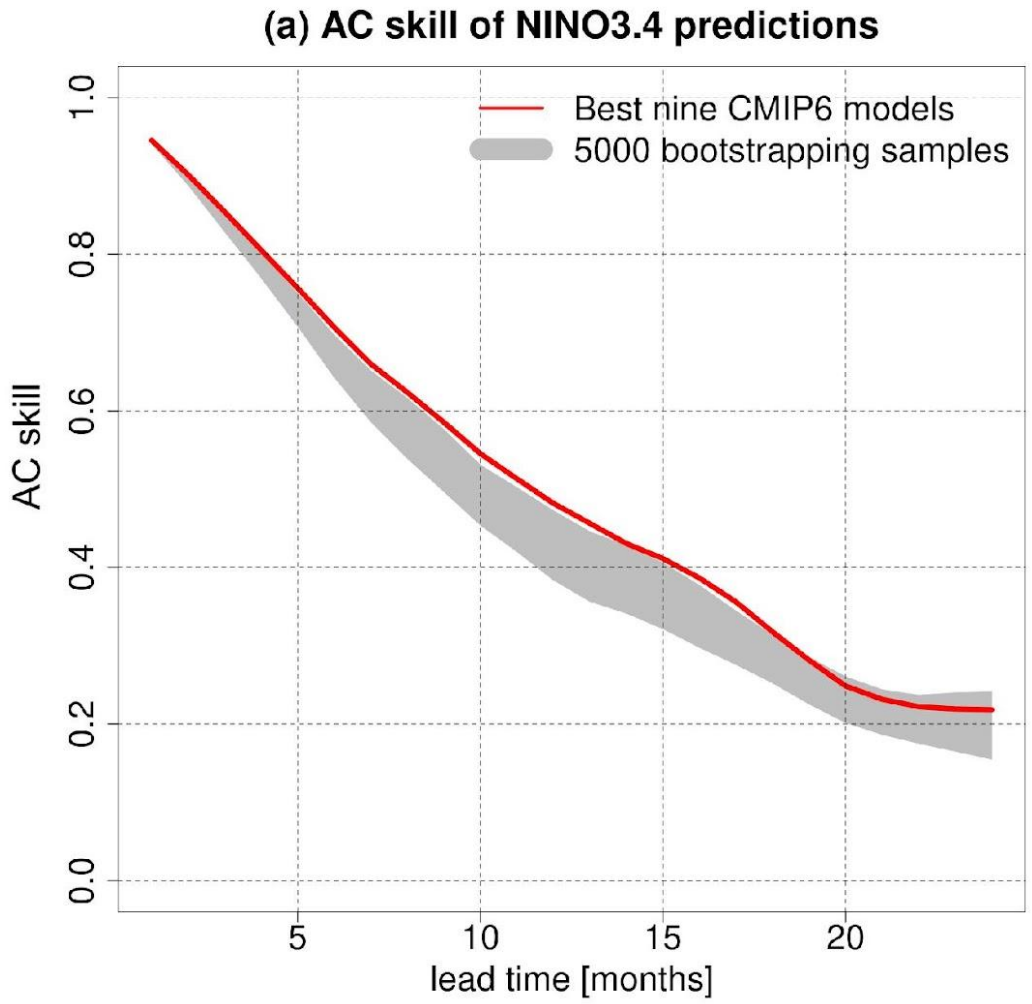
Figure: Seasonal mean AC skill of NINO3.4 predictions as a function of hindcast period on the horizontal axis and forecast lead time on the vertical axis.

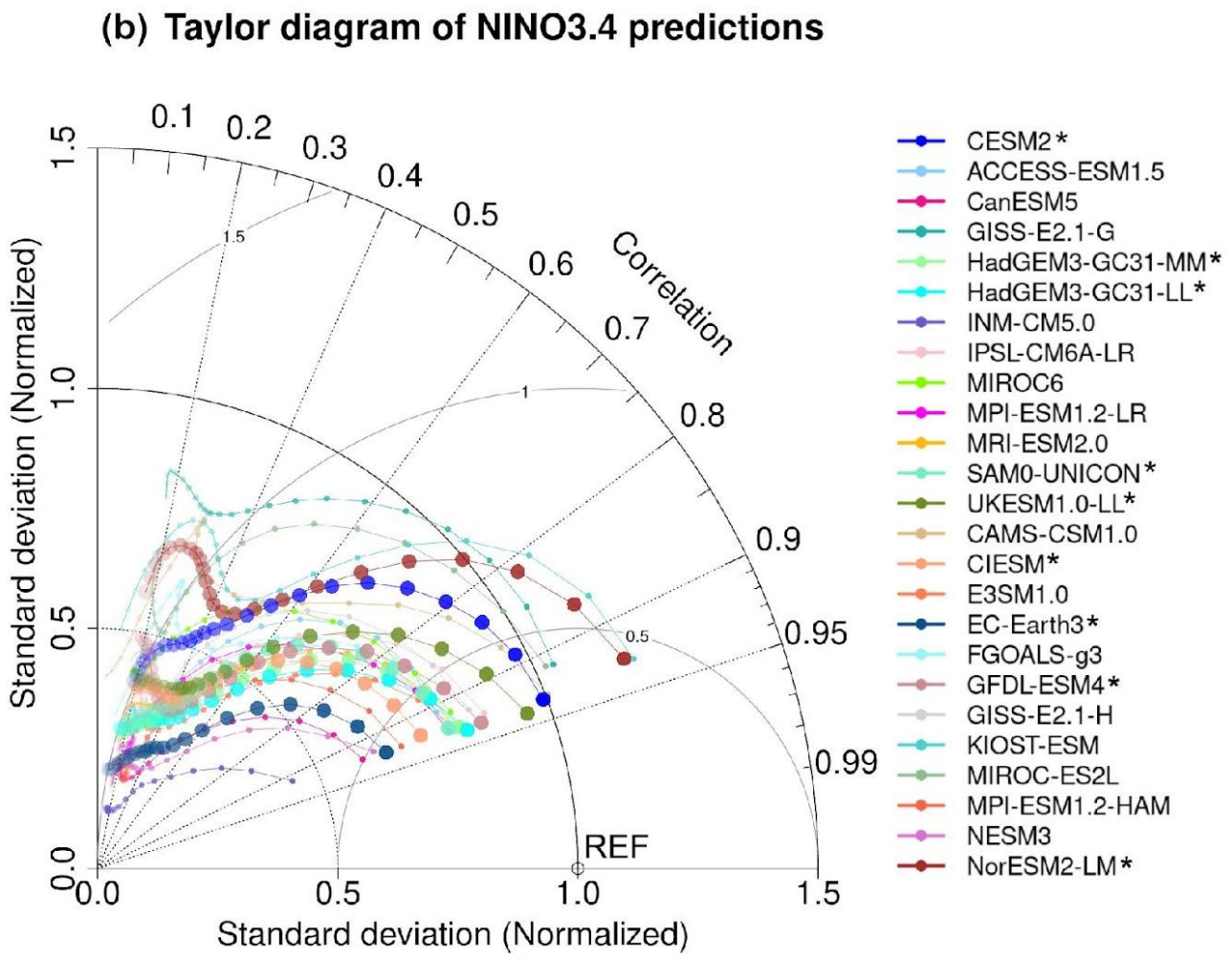

(a) SST+SSH
(b) SST-only
(c) Difference
Lead time [months]
24
20
16
12
8
4
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.15
0.1
0.05
0
-0.05
-0.1
-0.15
1890
1920
1950
1980
Years

Multi-decadal variation of ENSO forecast skill



Supplement


(a) AC skill of NINO3.4 predictions
Best nine CMIP6 models
5000 bootstrapping samples
AC skill
lead time [months]
0.0
0.2
0.4
0.6
0.8
1.0
5
10
15
20


(b) Taylor diagram of NINO3.4 predictions
Standard deviation (Normalized)
Correlation
REF
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
0.95
0.99
0.0
0.5
1.0
1.5
CESM2*
ACCESS-ESM1.5
CanESM5
GISS-E2.1-G
HadGEM3-GC31-MM*
HadGEM3-GC31-LL*
INM-CM5.0
IPSL-CM6A-LR
MIROC6
MPI-ESM1.2-LR
MRI-ESM2.0
SAM0-UNICON*
UKESM1.0-LL*
CAMS-CSM1.0
CIESM*
E3SM1.0
EC-Earth3*
FGOALS-g3
GFDL-ESM4*
GISS-E2.1-H
KIOST-ESM
MIROC-ES2L
MPI-ESM1.2-HAM
NESM3
NorESM2-LM*