UNIVERSITY OF COLORADO • CIRES • ESRL • PHYSICAL SCIENCES DIVISION

Diagnosing Externally-forced Changes in ENSO Dynamics and Predictability within a CGCM Large Ensemble

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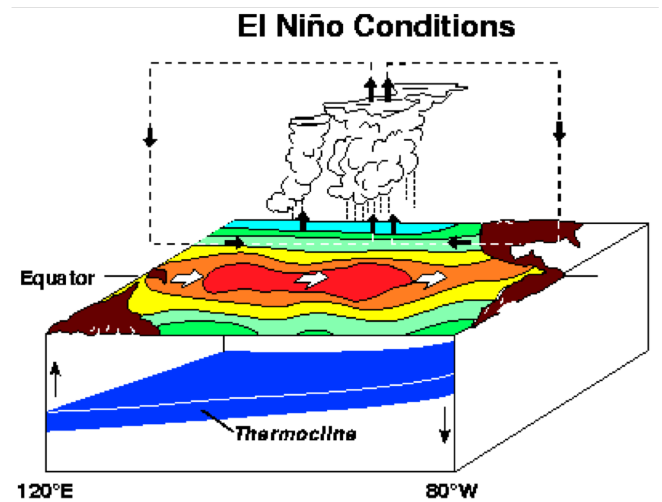

US CLIVAR Large Ensembles Workshop • 24-26 July 2019

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(And if so, how can we tell?)

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- But: ~500 years may be needed to capture the full diversity of ENSO events, while "good" records are ~100 years (or so)
  - Observed changes may still reflect random natural variability
- CESM-LE has 800 yrs of data for every 20-yr period
  - Examine how dynamics/predictability change from one period to the next from 1950-2069, *for this model*

Empirical model of dynamics: *Linear inverse model (LIM)*

If nonlinearities are mostly *fast* then on slower climate time scales they are essentially *unpredictable*, apart from a linearly parameterizable portion.

Empirically model climate anomaly *evolution* with linear stochastically forced dynamics:

$$d\mathbf{x}/dt = \mathbf{L}\mathbf{x} + \mathbf{S}\eta$$

x(*t*): series of **maps**, **L**: stable operator, **S**η : white noise (also **maps**)

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- Determine $\mathbf{L}$ from one-lag covariance matrix ("multivariate AR1")
- Use low order climate state $\mathbf{x}$ (here, just monthly SST and SSH anomalies in reduced PC space, or 36 degrees of freedom)
- (Ensemble mean) forecasts for lead τ : $\mathbf{x}(t + \tau) = exp(\mathbf{L}\tau)\mathbf{x}(t)$; <u>skill is comparable to operational CGCMs</u>
- **Multivariate, so an anomaly can be found from $exp(\mathbf{L}\tau)$ that grows most over time interval τ → greatest skill occurs when initial conditions ≈ this "optimal"**

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For each 20-yr period:

1. *Determine* **L** *from 40-member ensemble anomalies (relative to evolving ensemble mean)*
2. *Determine "optimal" initial condition, its amplification (growth factor), and what it evolves into, for varying lead times*
3. *Determine "perfect-model" forecast skill, using the LIM to predict within the CESM-LE*

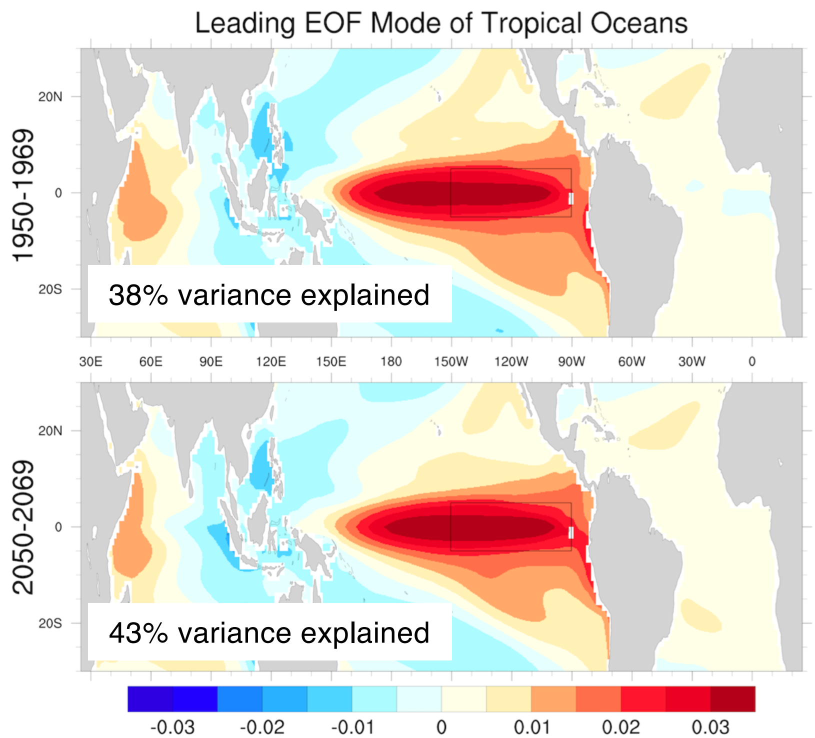
   "cross-validate": withhold each ensemble member in turn, construct LIM, forecast using withheld data

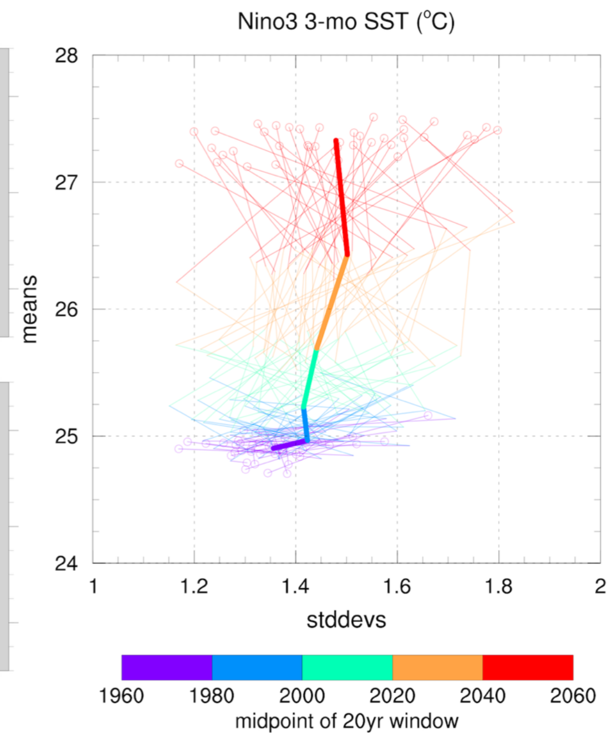
ENSO gets stronger in the CESM-LE

Left: Dominant SST pattern (EOF) has little change, but explains more variability

Right: In Niño3 region, ensemble-mean ENSO amplitude (x-axis) increases, especially in early 21st century, while mean (y-axis) warming occurs

thin lines : ensemble members
thick line: ensemble mean





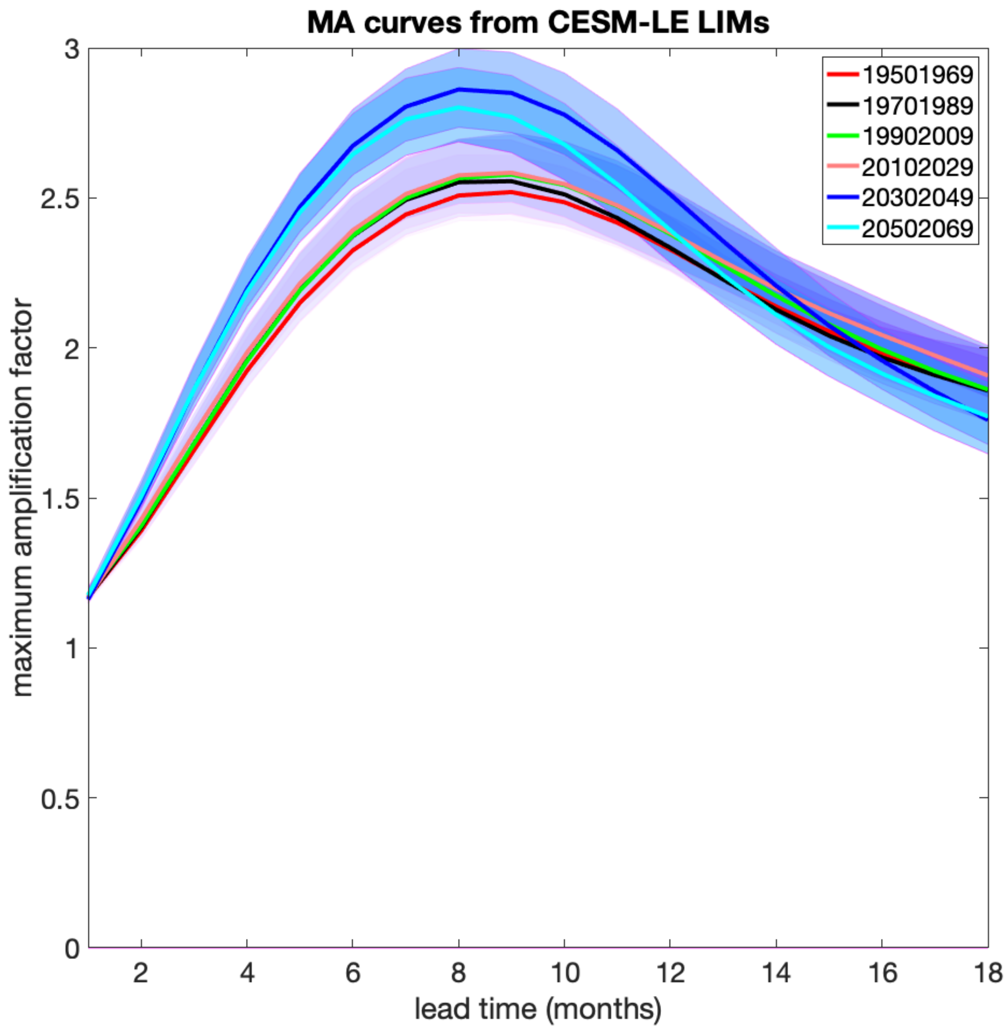
Courtesy of Candida Dewes

Maximum possible ENSO amplification changes little until it increases in the mid 21st century

Growth factor as a function of lead time is plotted as the "Maximum amplification" (MA) curve.

MA curves are determined for each 20-yr period.

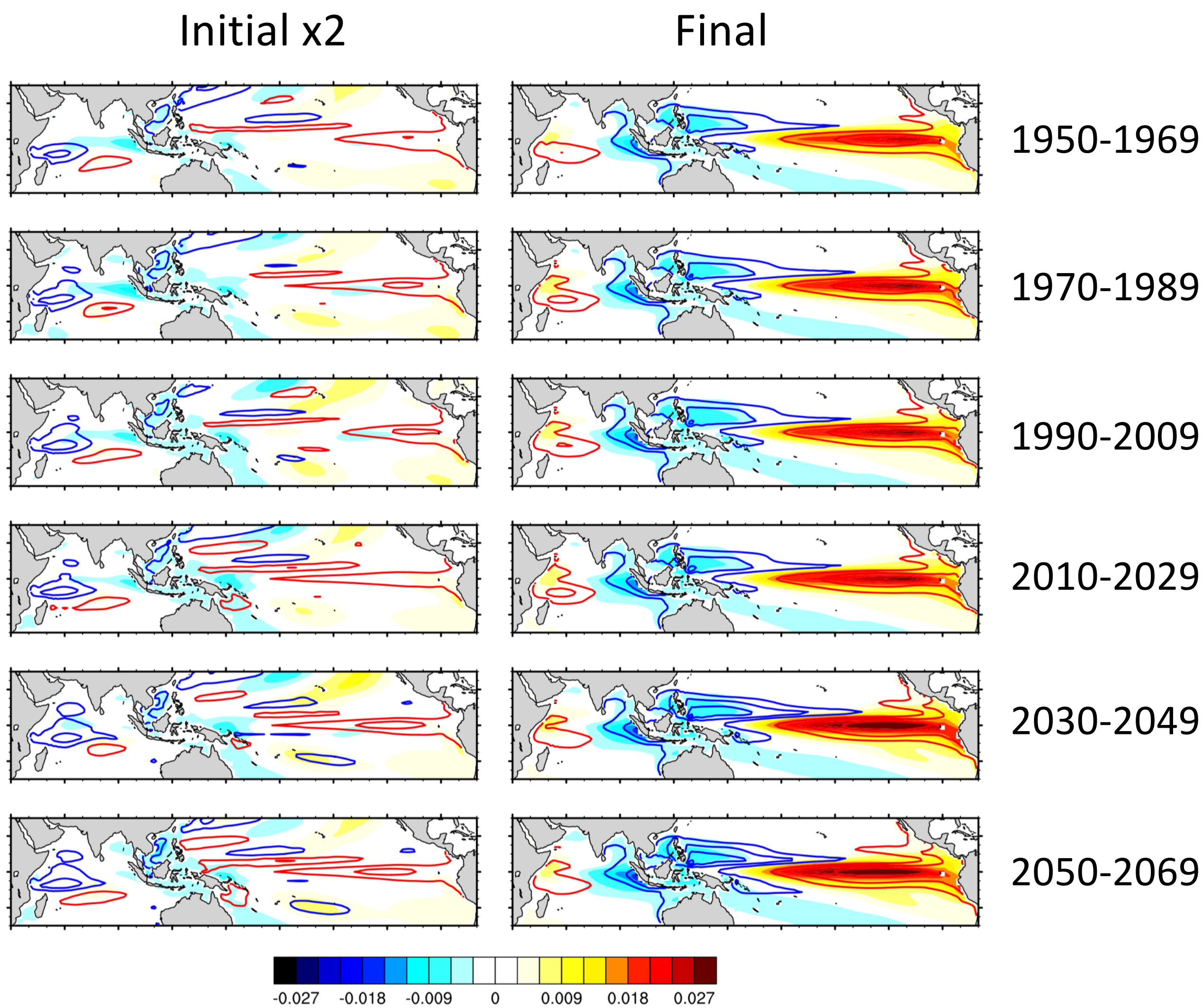
Shading represents estimate of sampling uncertainty: 5th-95th percentile range of MA curves based on random draws (*without* replacement) of 20-member subensembles



Change to optimal ENSO growth

Initial (“optimal”) anomaly and final anomaly (6 months later), determined from LIM for each 20-yr period

SST: shading
SSH: contours



Amplification of "ENSO flavor" structure increases fairly steadily throughout the century

Growth factor of the second growing structure as a function of lead time is plotted as the "Maximum amplification" (MA) curve.

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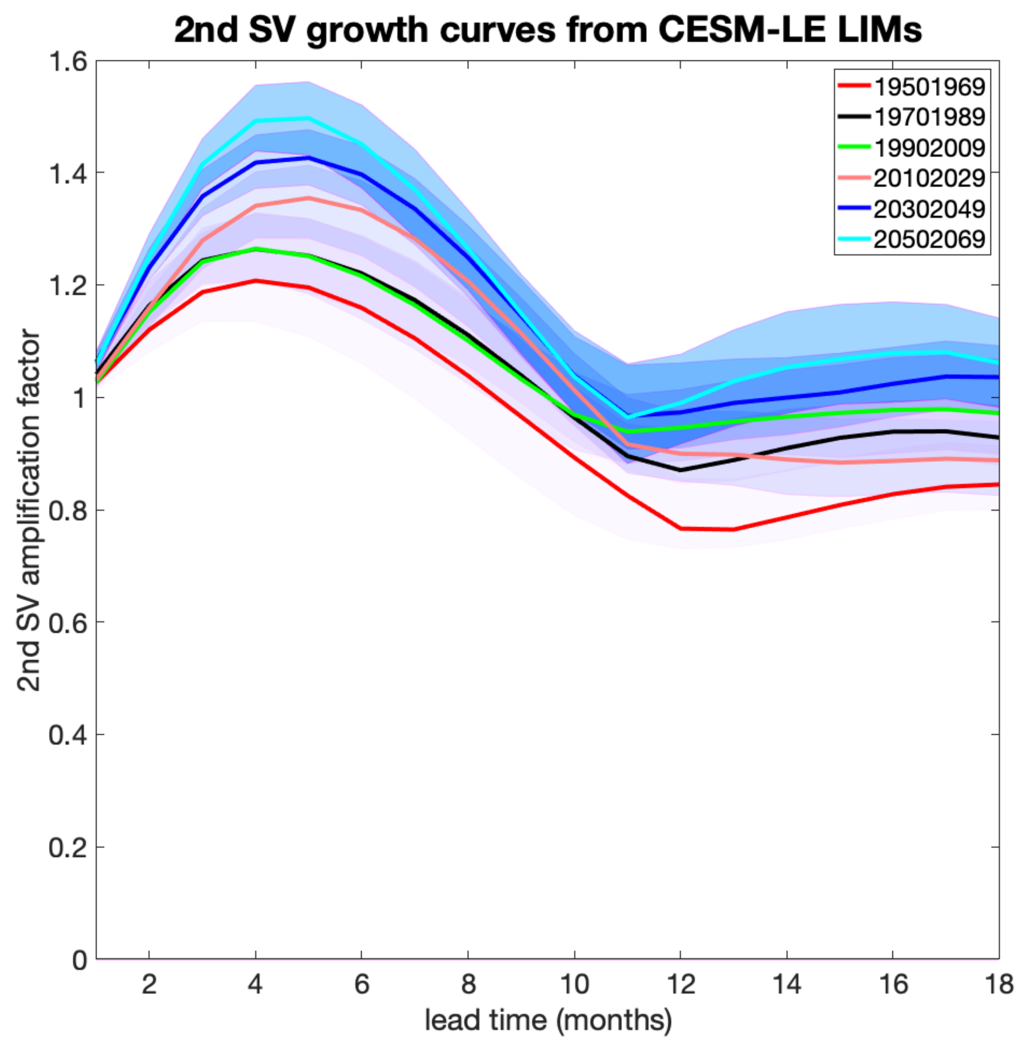
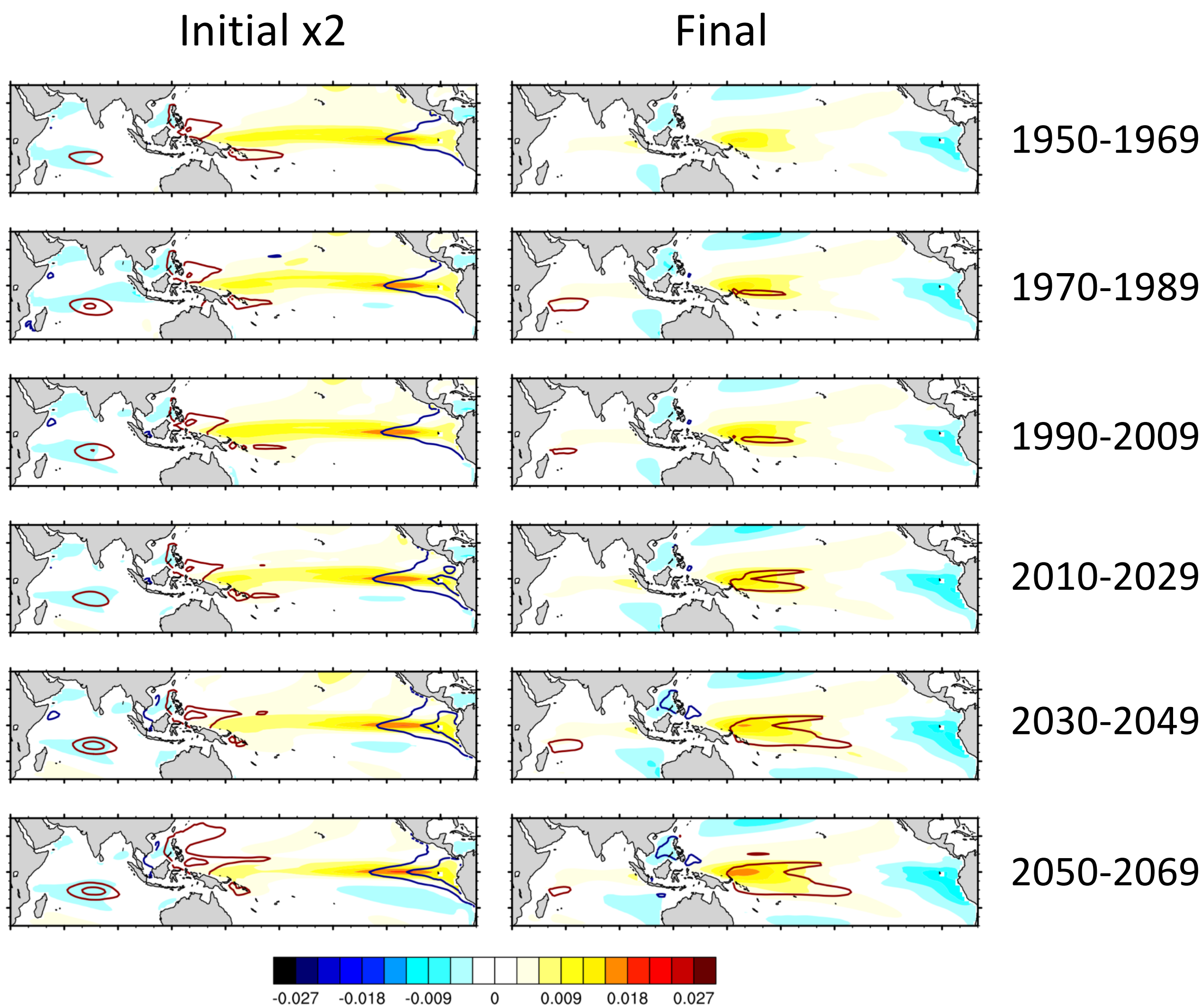
Shading represents estimate of sampling uncertainty: 5^{th}-95^{th} percentile range of growth curves based on random draws (*without* replacement) of 20-member subensembles



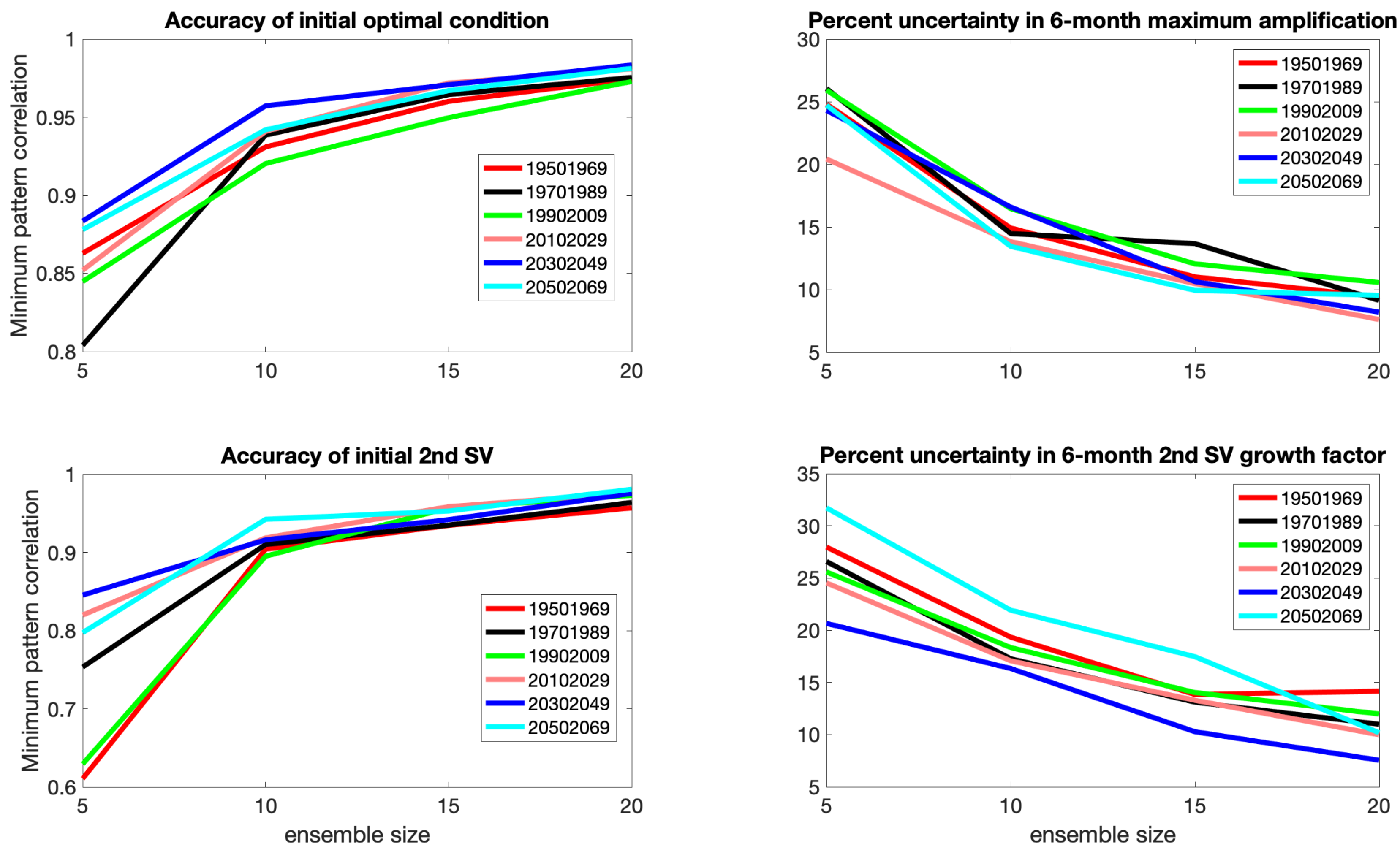
Change to 2nd growing structure ("ENSO flavor")

Second growing structure: initial anomaly and final anomaly (6 months later), determined from LIM for each 20-yr period

SST: shading
SSH: contours



How large an ensemble do we need?

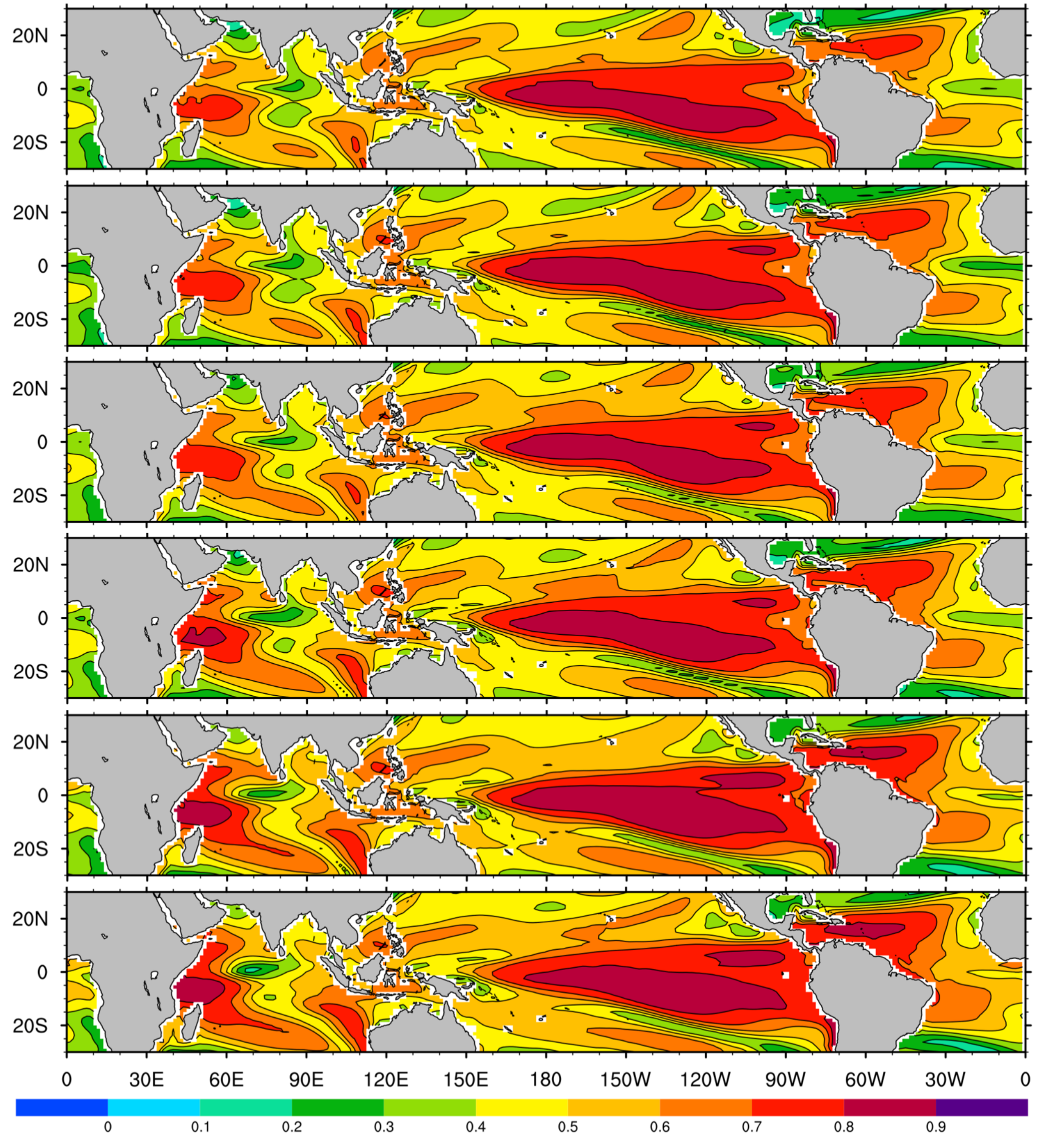


(Slightly) Increasing predictability

Panels show skill of 6-month lead LIM forecasts, measured by local anomaly correlation.

Small increase in skill ~2030, but mostly not significant (except perhaps in western Indian Ocean and tropical Atlantic).

Recall anomalies are relative to time-evolving trend (no trend forecast)



1950-1969

1970-1989

1990-2009

2010-2029

2030-2049

2050-2069

Conclusion

- A large ensemble (CESM-LE) dataset can provide enough data to determine changes in ENSO dynamics (20 members may be enough)
- In this CESM1 model, external forcing has caused little change in ENSO dynamics in the 20th century, but is projected to make ENSO grow more strongly, especially its (western) Pacific flavor
- However, these changes are *small* and do not significantly impact ENSO predictability