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FEBRUARY 4, 2026

Reducing Uncertainty in Projections of US Hydroclimate

An Analog Approach

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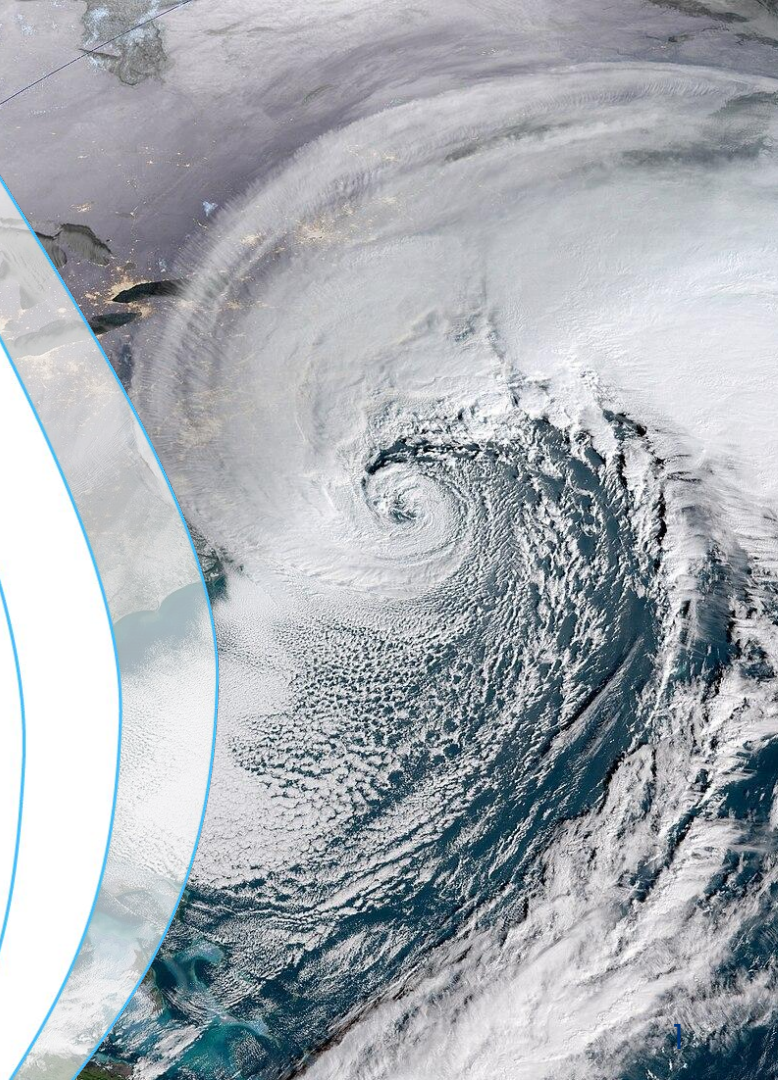
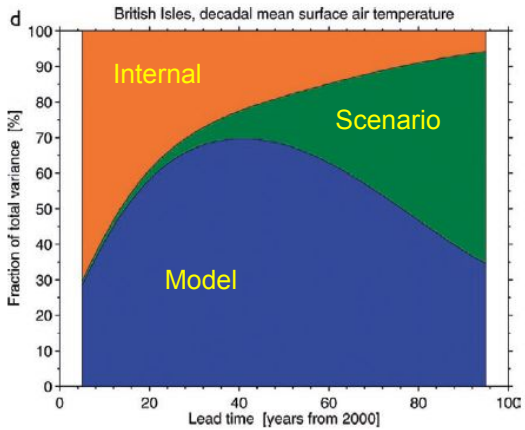
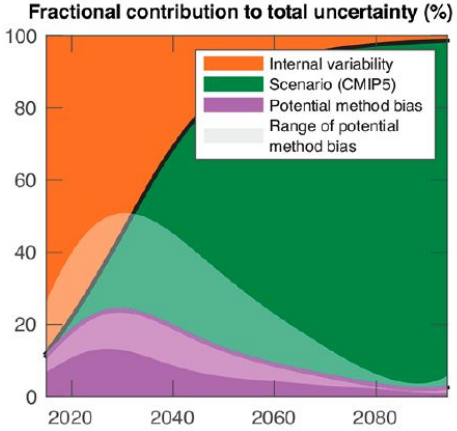


Regional Climate Projection Uncertainty



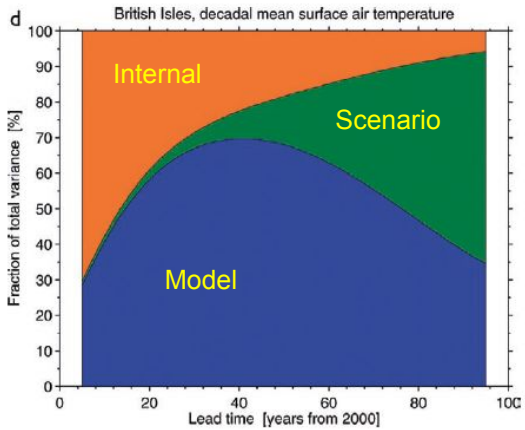
Hawkins & Sutton (2009)



Lehner et al. (2020)

Internal variability is a dominant source of uncertainty in decadal projections of future regional climate.

Regional Climate Projection Uncertainty



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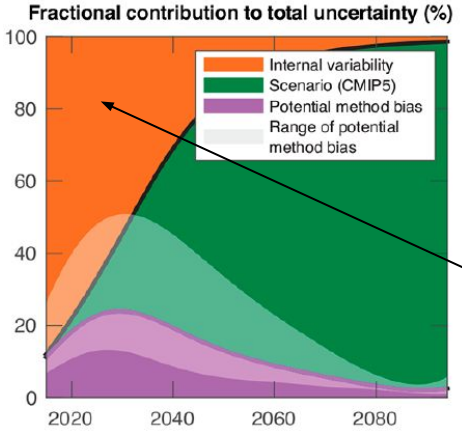


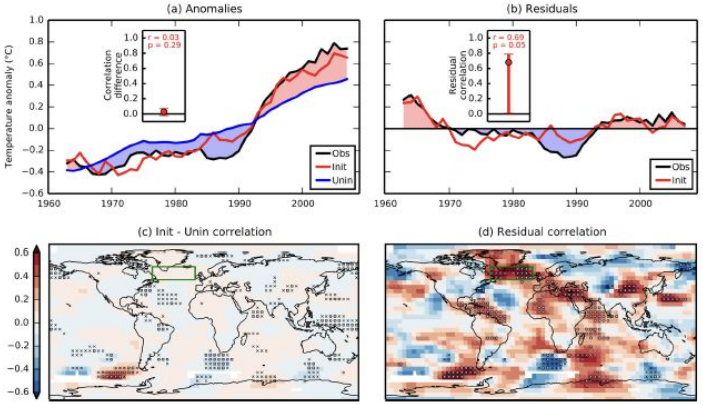
Lehner et al. (2020)

The fraction of internal variability that is potentially predictable (vs. irreducible) remains unclear.

Internal variability is a dominant source of uncertainty in decadal projections of future regional climate.

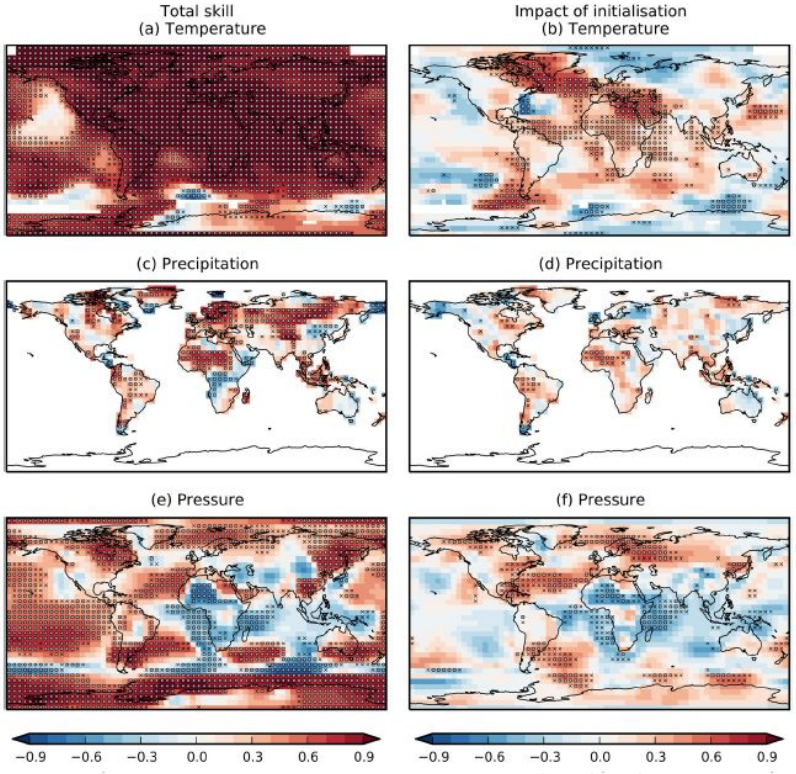
Initialized Decadal Prediction

Internal variability uncertainty can be reduced through initialization. Added value from initialization is most evident by focusing on the “residual” after removing the forced signal.



Smith et al. (2019)

Skill for FY2-9 (CMIP5 DCPP):



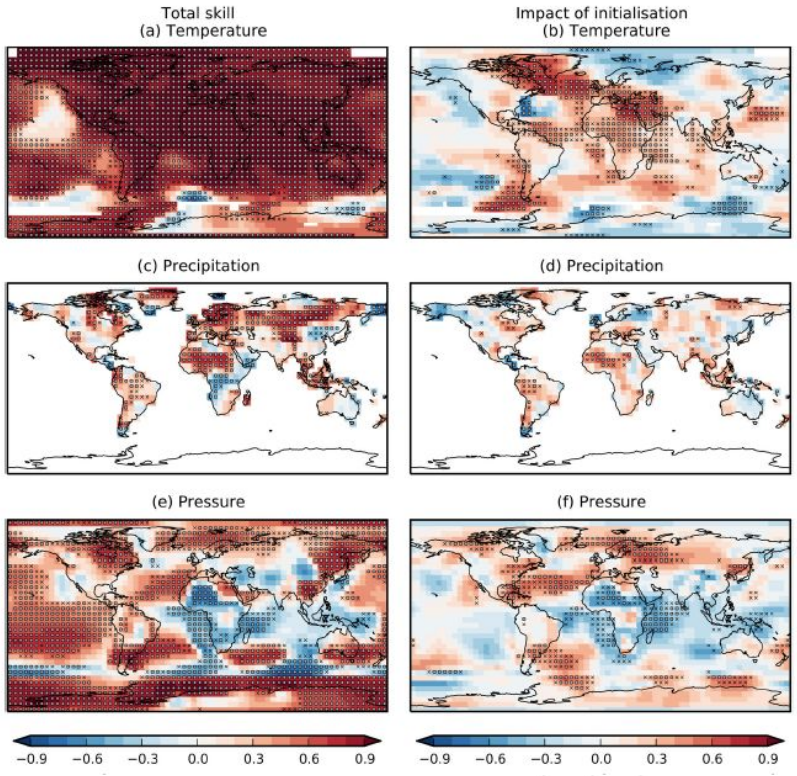
Initialized Decadal Prediction

DCPP systems generally show:

good skill improvement related to Atlantic Multidecadal Variability (AMV).

low skill improvement for Pacific Decadal Variability (PDV).

Skill for FY2-9 (CMIP5 DCPP):



Overview

Aim:

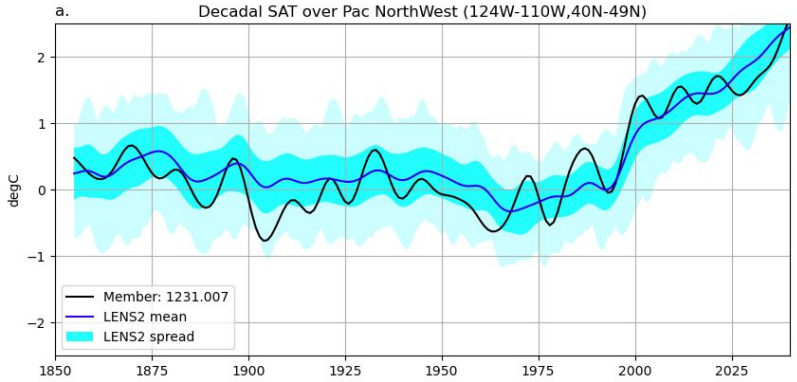
Assess the potential to reduce uncertainty for future decadal hydroclimatic change over CONUS by constraining potentially predictable, large-scale internal modes of variability (iMOVs).

Methods:

- Analyze the CESM2 Large Ensemble (CESM2-LE; Rodgers et al. 2021)
  - 100-member ensemble
  - 1850 to 2100
  - CMIP6 historical/SSP3-7.0 forcing
- Separate low frequency (10-year filtered) internal/forced variability (annual mean fields)
- Evaluate skill of “iMOV” analog ensembles in perfect model framework

Potential Predictability

Surface air temperature (SAT) over Pacific Northwest:

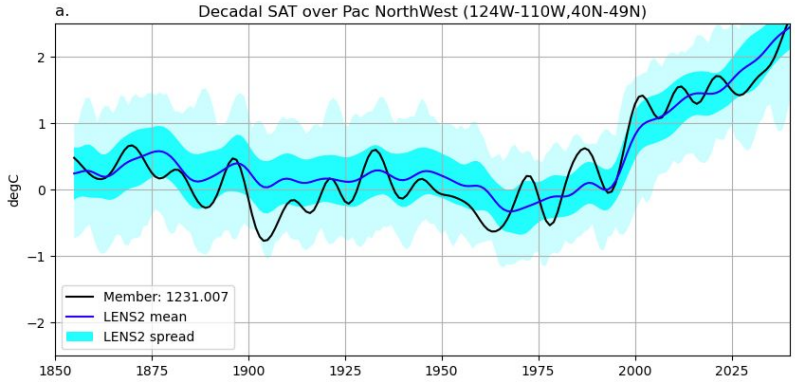


Skill (1871-2025):
r=0.88
msss=0.74
nrmse=0.51
ncrps=0.29

Skill of uninitialized historical ensemble at predicting evolution in a single member using “leave one out” approach.

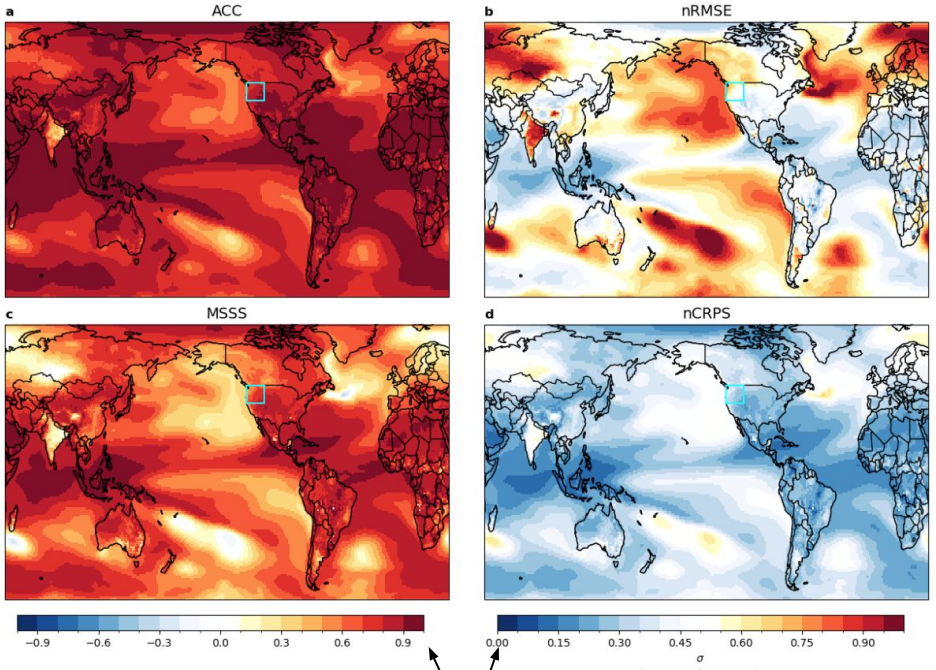
Potential Predictability

Surface air temperature (SAT) over Pacific Northwest:



Skill (1871-2025):
r=0.88
msss=0.74
nrmse=0.51
ncrps=0.29

Forecast Skill (1871-2025 verification):

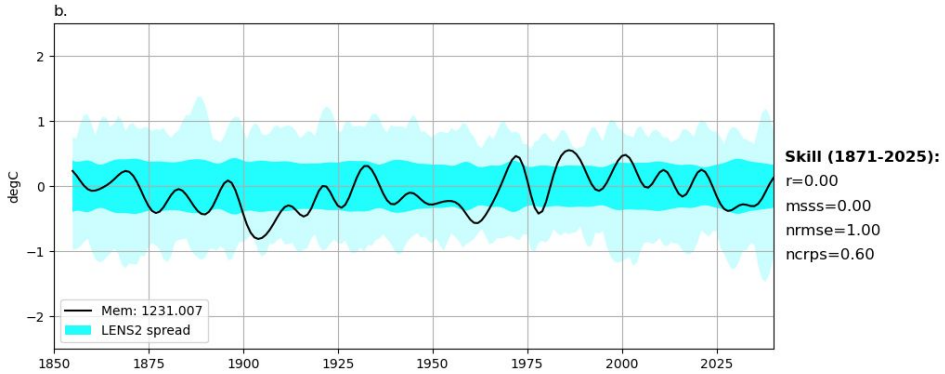


Forced large ensemble yields widespread good skill...

Perfect Skill

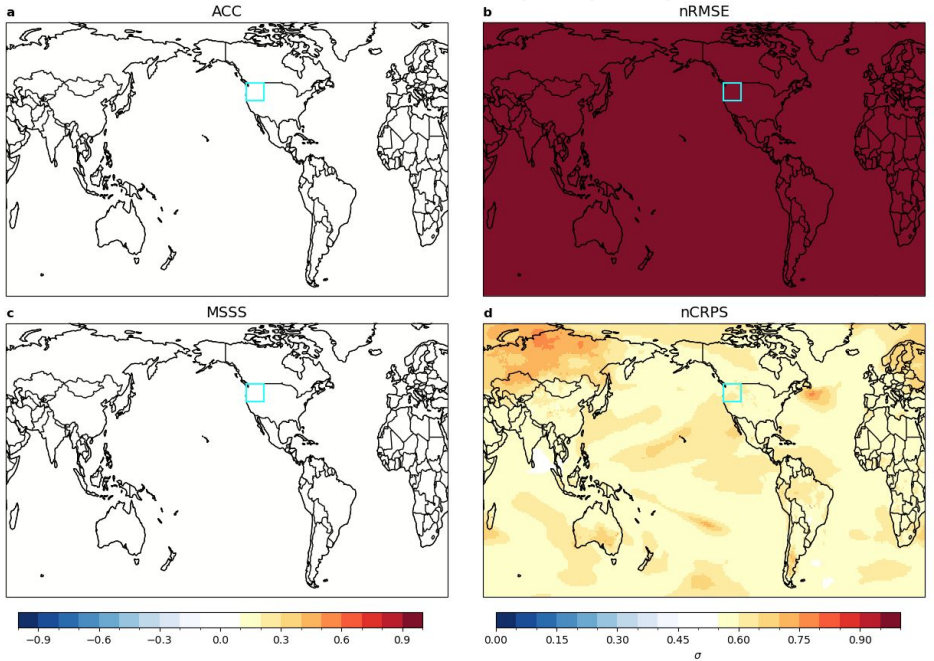
Potential Predictability

Residual (internal) SAT over Pacific Northwest:



Forced large ensemble yields widespread good skill…
but low residual skill (by definition).

Forecast Skill (1871-2025 verification):



Perfect Skill

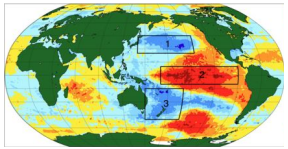
iMOV Analog Method

iAMV:

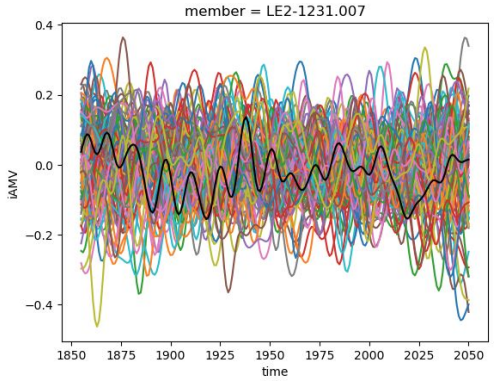
<iSST>, 0°–65°N in Atlantic

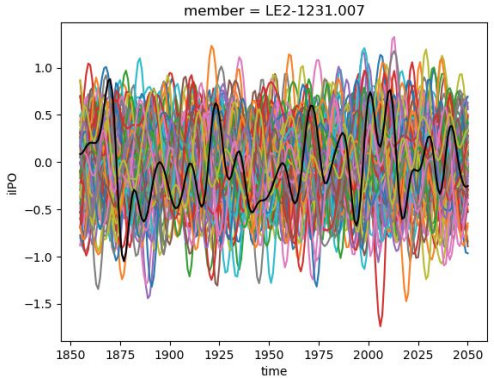
iIPO:

<iSST>, tripole index

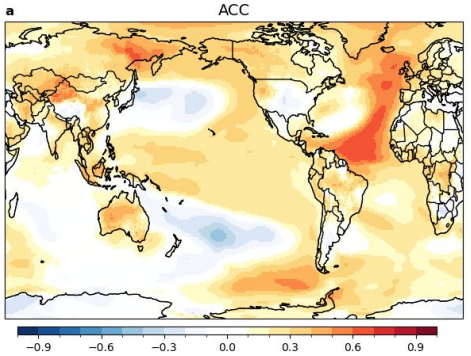


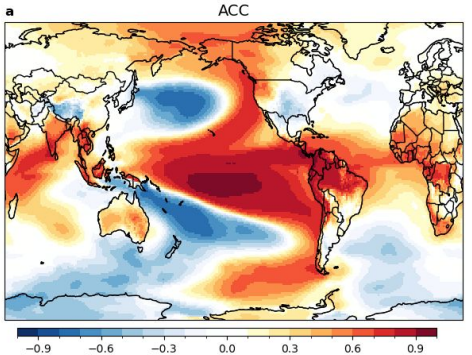
Internal MOV (iMOV):



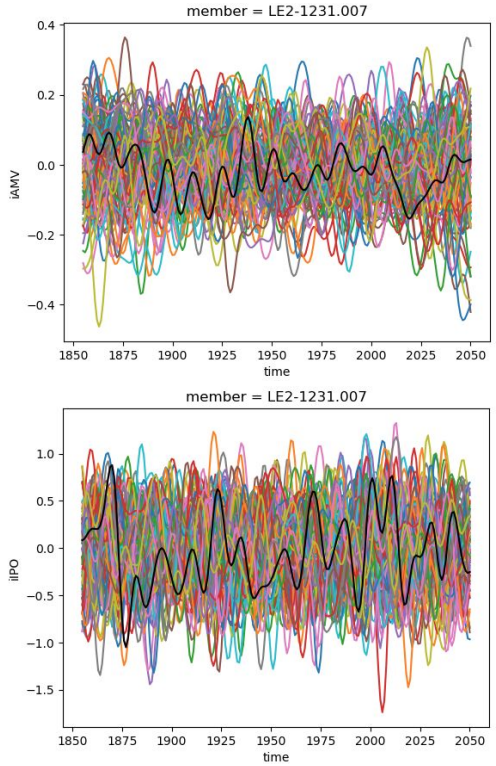


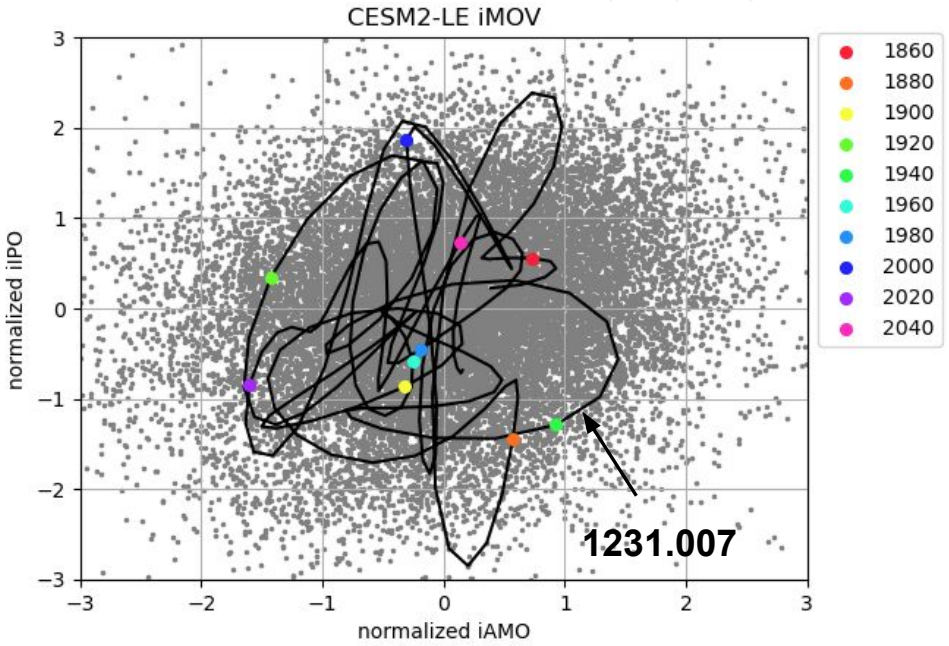
SAT regression on iMOV:



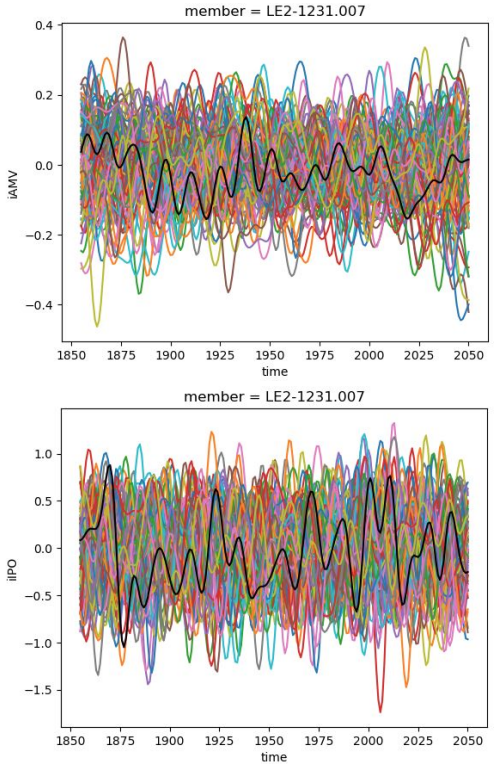


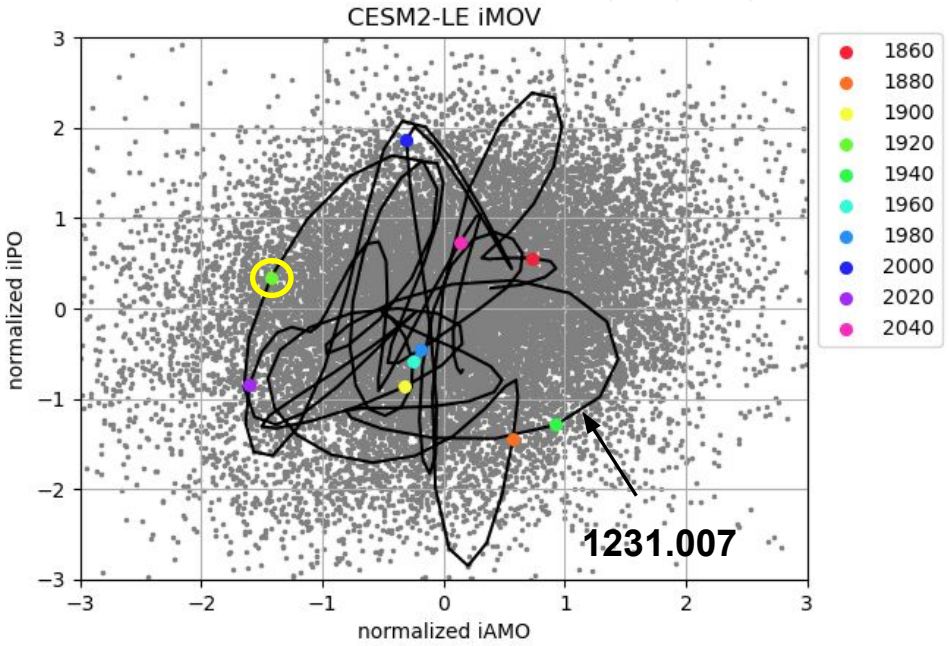
iMOV Analog Method





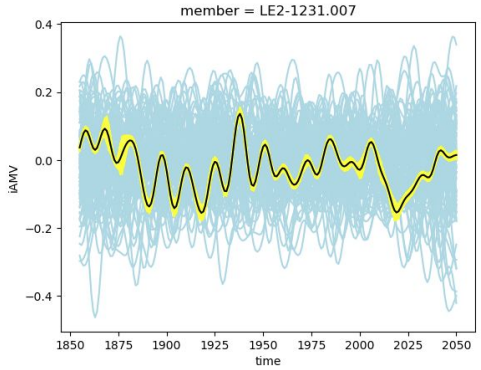
iMOV Analog Method

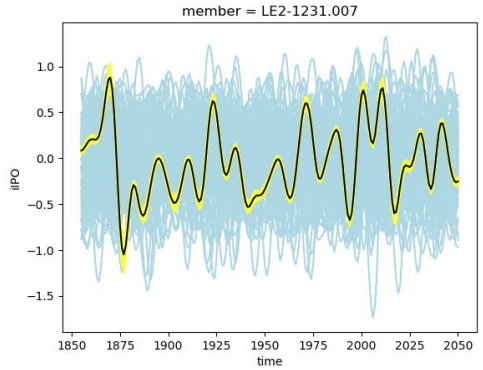


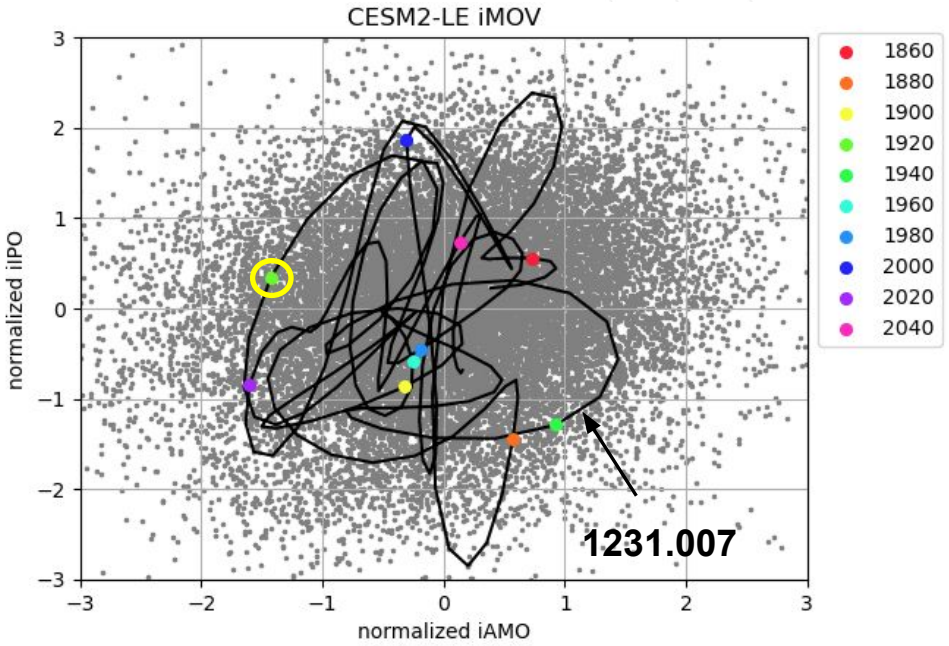


Construct 100-member ensemble whose large-scale internal variability (iAMV, iIPO , & associated teleconnections) matches that of target member

iMOV Analog Method

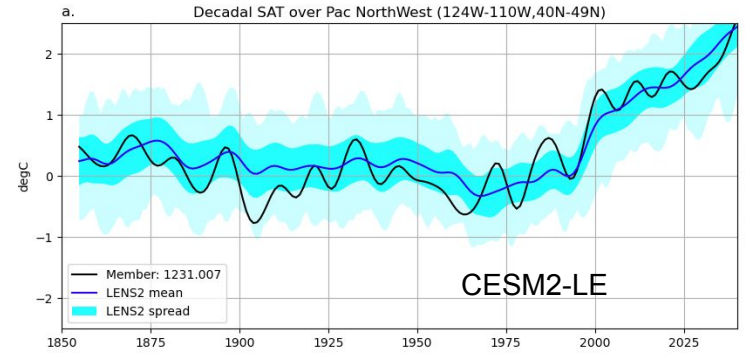




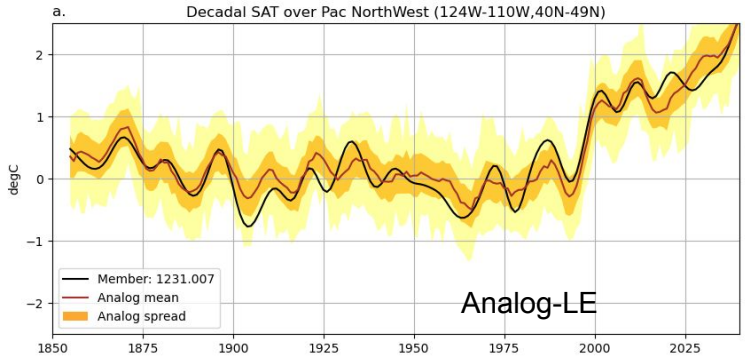


Construct 100-member ensemble whose large-scale internal variability (iAMV, iIPO , & associated teleconnections) matches that of target member: "iMOV Analog Ensemble".

Potential Predictability (Analog)



Skill (1871-2025):
r=0.88
msss=0.74
nrmse=0.51
ncrps=0.29

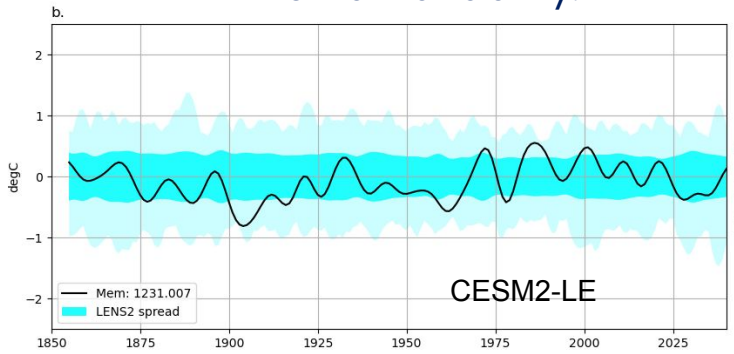


Skill (1871-2025):
r=0.94 } higher
msss=0.86
nrmse=0.37 } lower
ncrps=0.22

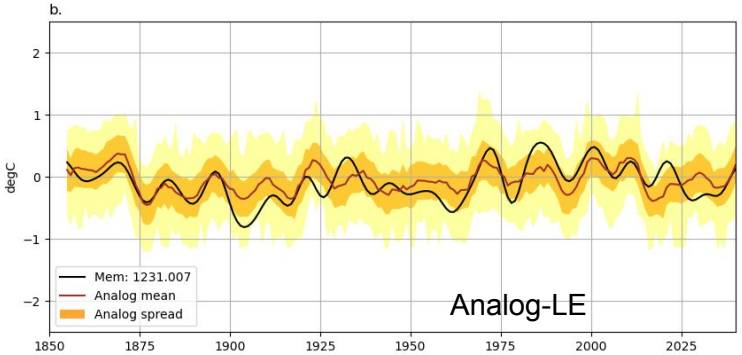
Constraining internal variability related to large-scale MOVs can substantially reduce uncertainty in regional climate projections.

Potential Predictability (Analog)

Internal variability:



Skill (1871-2025):
r=0.00
msss=0.00
nrmse=1.00
ncrps=0.60

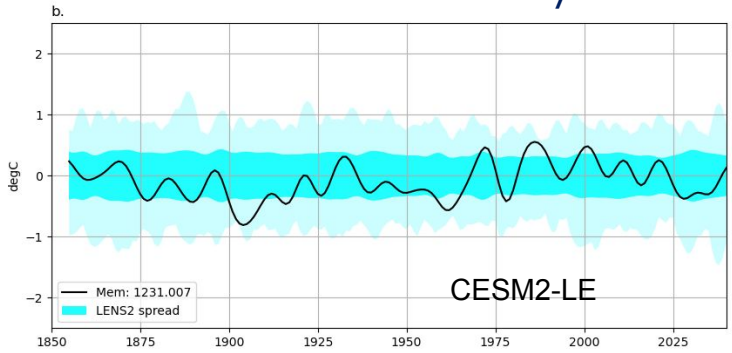


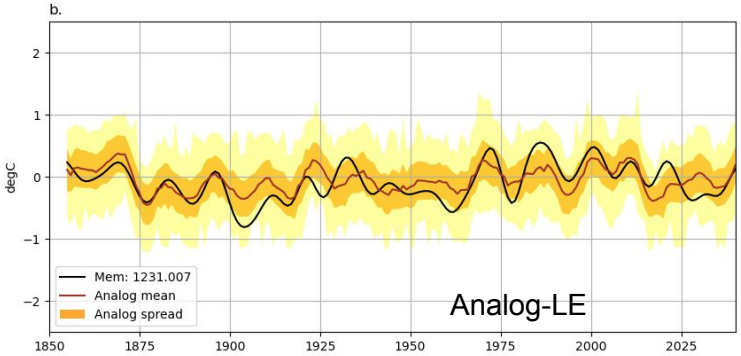
Skill (1871-2025):
r=0.65
msss=0.42 } higher
nrmse=0.76
ncrps=0.45 } lower

Constraining internal variability related to large-scale MOVs can substantially reduce uncertainty in regional climate projections.

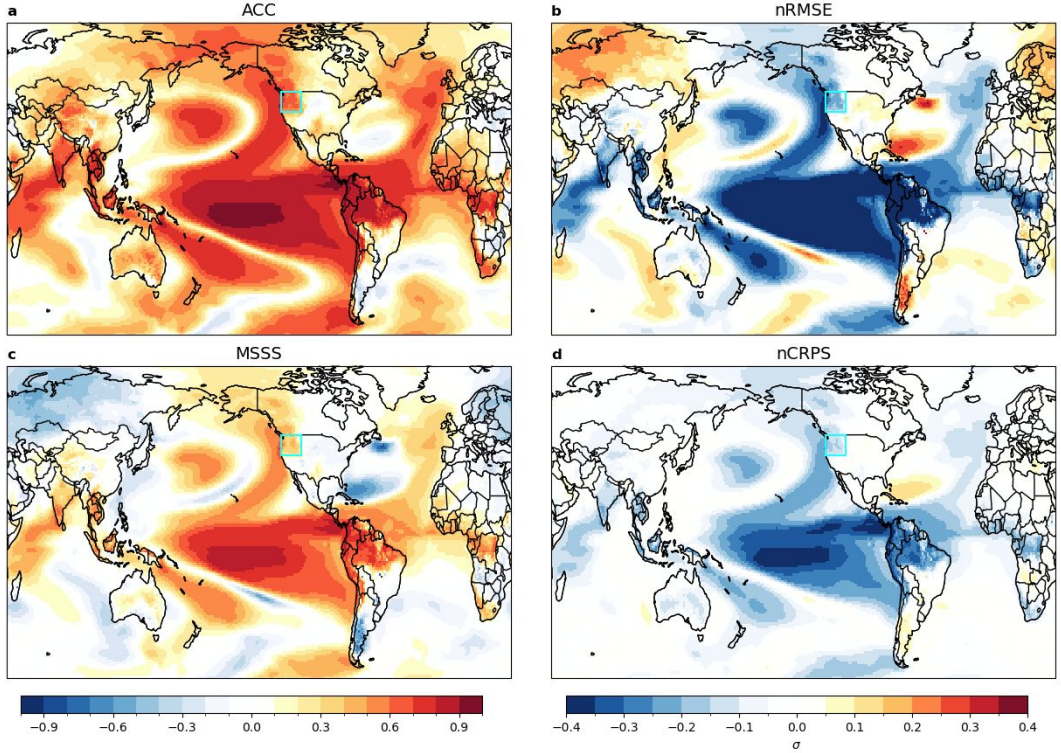
Potential Predictability (Analog)

Internal variability:





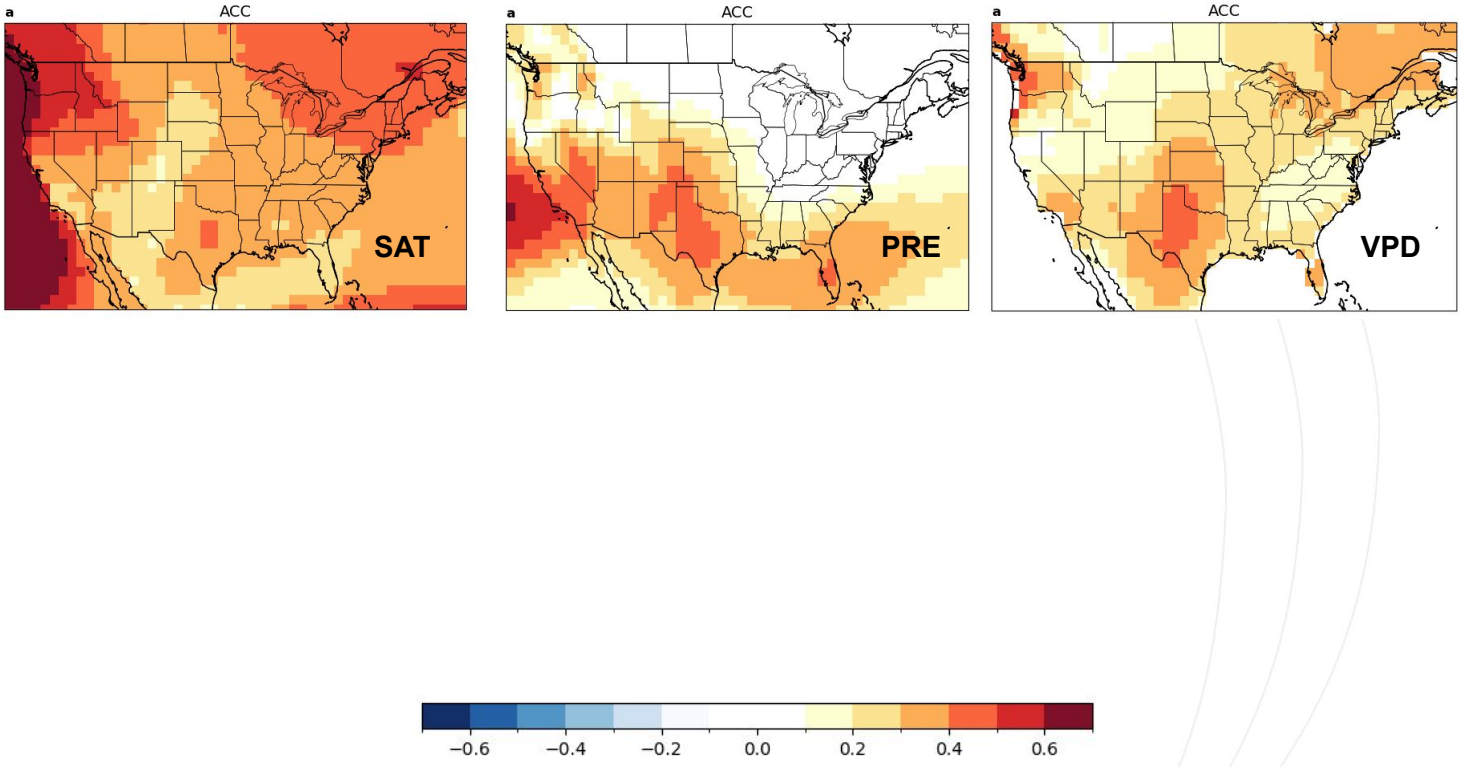
Analog Skill Improvement:



Potential Predictability (Analog)

Mean (over all target members):

Analog Skill Improvement:

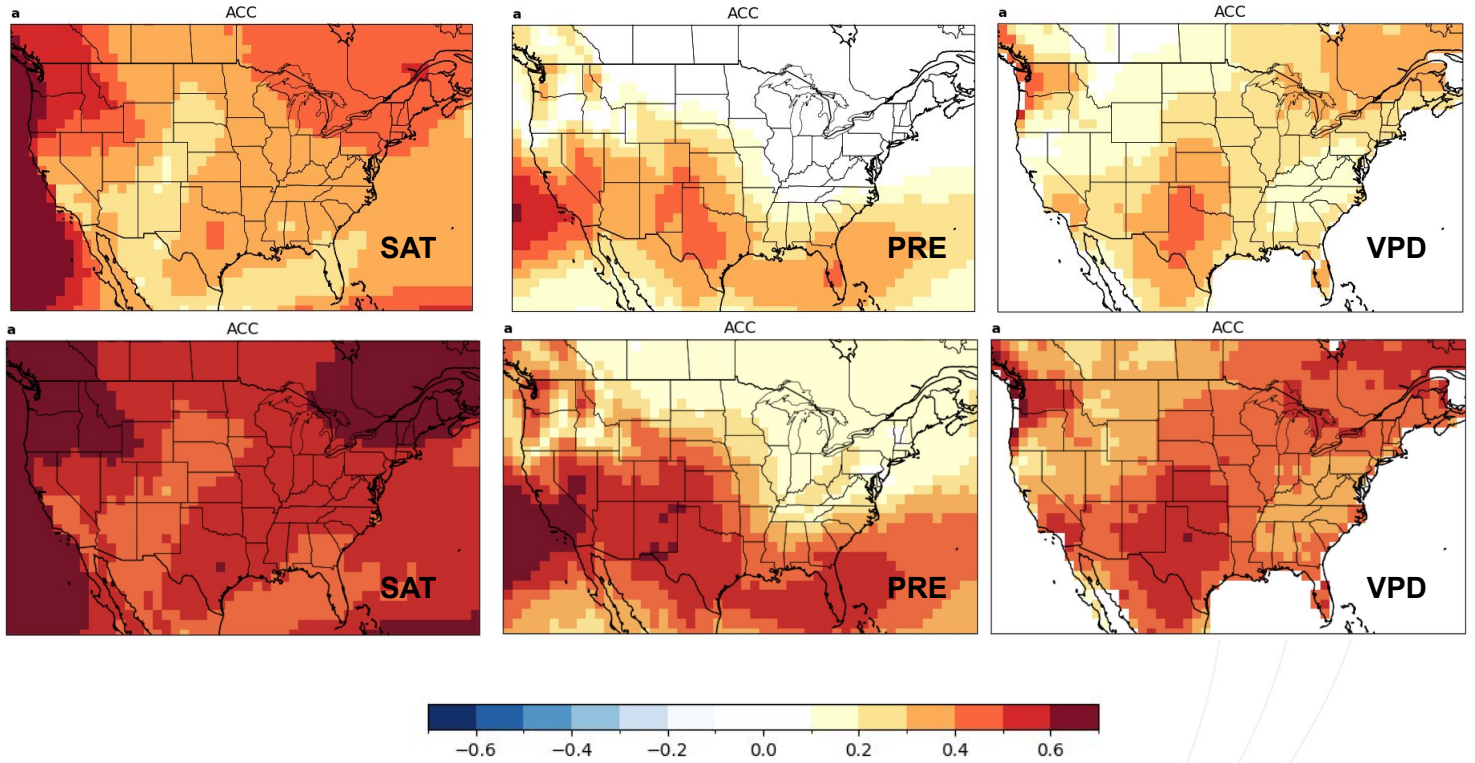


Potential Predictability (Analog)

Analog Skill Improvement:

Mean (over all target members):

90th percentile:

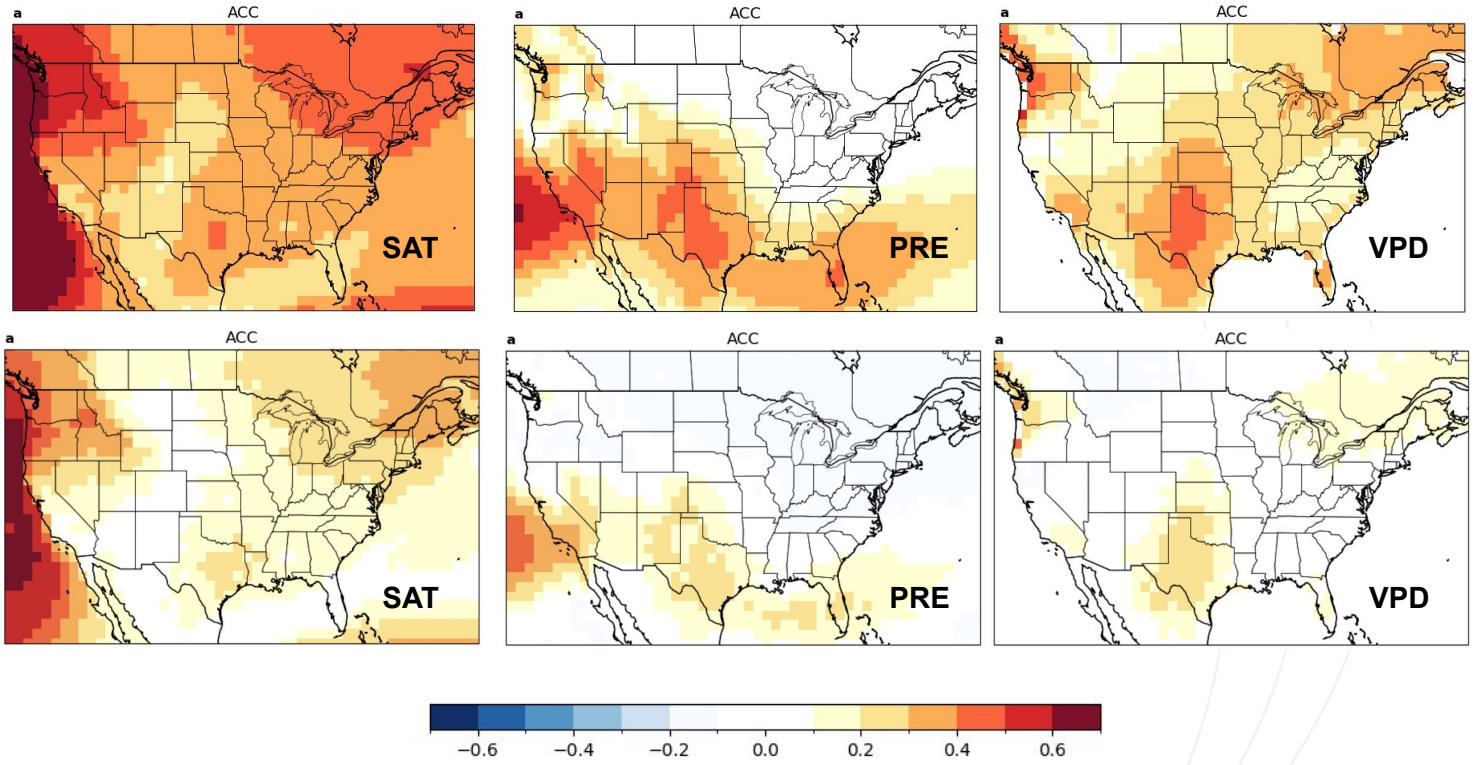


Potential Predictability (Analog)

Analog Skill Improvement:

Mean (over all target members):

10th percentile:



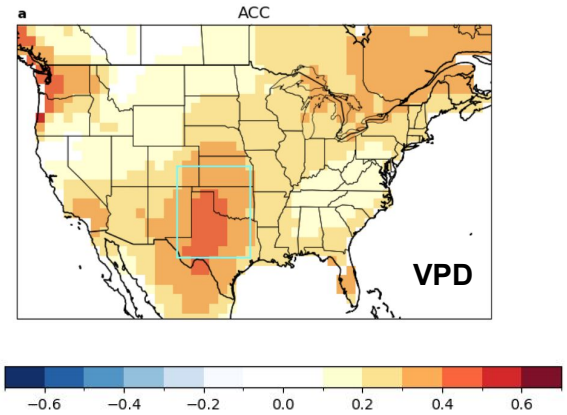
Summary & Next Steps

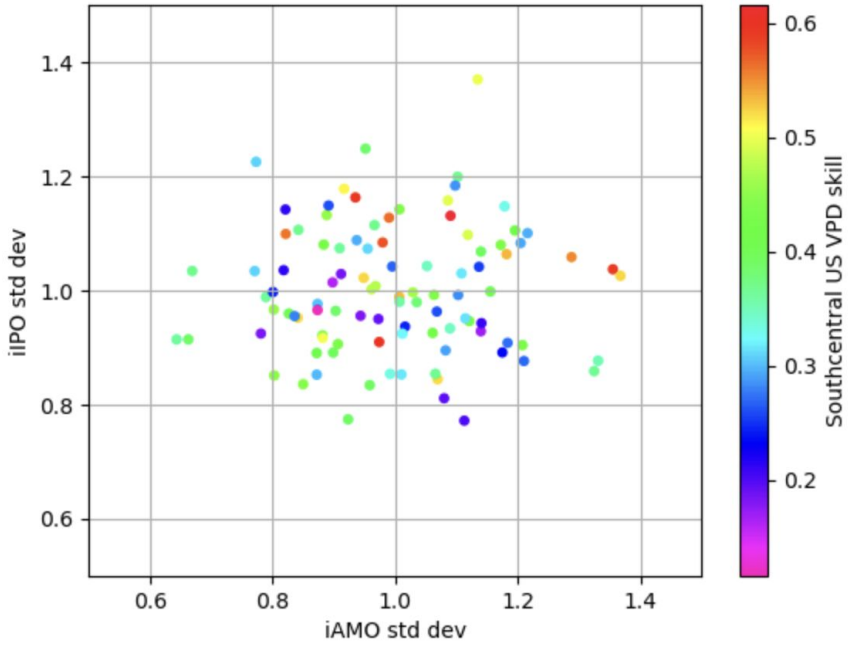
- MOV-matching analog technique can significantly reduce uncertainty in regional decadal climate variability in a perfect model framework (offering insight into decadal predictability limits*).
- CONUS hydroclimate variability (e.g., vapor pressure deficit), in particular, exhibits potentially exploitable relationships to large-scale, decadal ocean boundary conditions.
- Work is underway to extend the technique (descriptive to predictive, perfect-model to real-world, use of multi-model large ensembles).
- What contributes to skill spread? How predictable is real-world internal variability?

* With caveats regarding model fidelity

Potential Predictability (Analog)

Analog Skill Improvement:

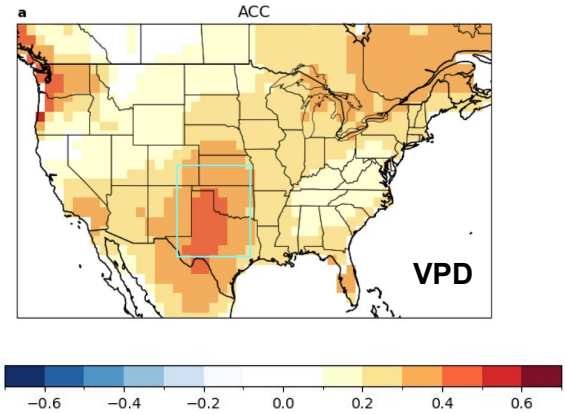


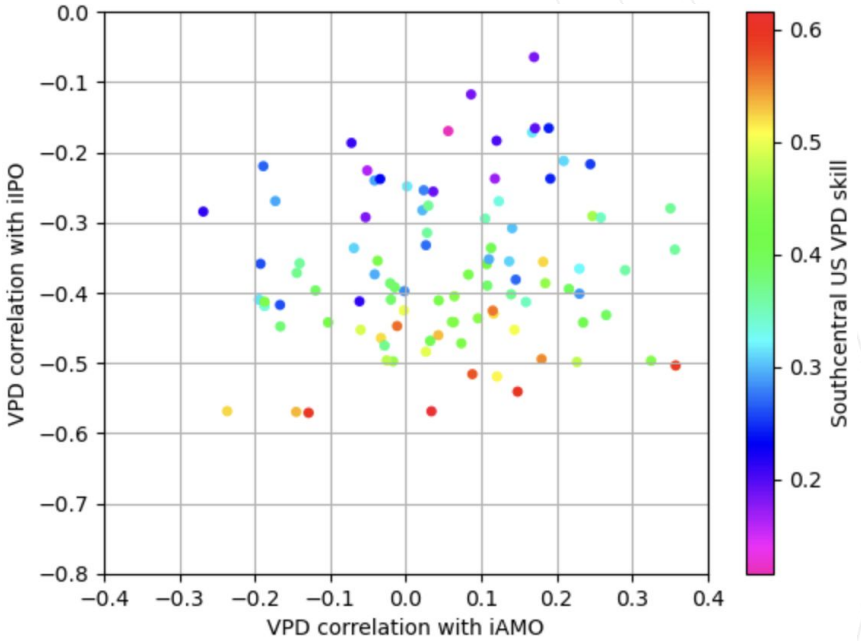


No clear relation between VPD analog skill over southcentral CONUS and strength of iMOVs.

Potential Predictability (Analog)

Analog Skill Improvement:





Clear relation between VPD analog skill over southcentral CONUS and strength of iIPO/VPD teleconnection in target member.