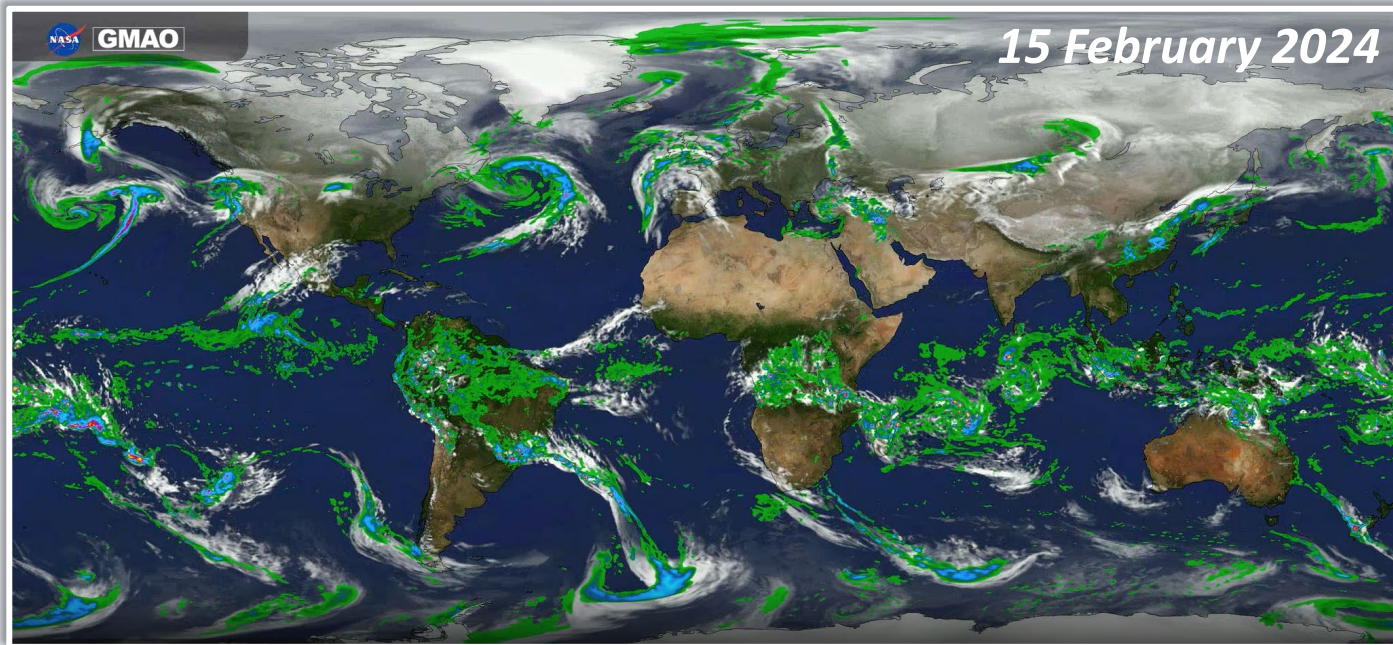


Future Changes in Modes of Internal Variability: A Case Study of the North Pacific Atmospheric Circulation



Clara Deser (Climate Analysis Section, NSF-NCAR)

CESM Tutorial 10 July 2025

Anthropogenic Emissions

**Sulfate &
Black Carbon
Aerosols**



**Well-mixed
Greenhouse
Gases**



- **Changes in the Mean State**
- **Changes in Variability**

Anthropogenic Emissions

**Sulfate &
Black Carbon
Aerosols**



**Well-mixed
Greenhouse
Gases**



**How will the characteristics of internal variability change with climate change?
(spatial patterns, amplitudes, frequency...)**



- **Initial-condition Large Ensembles**



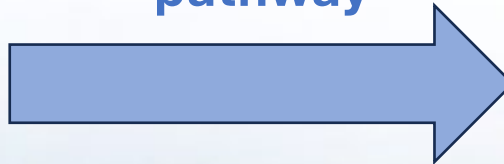


- Initial-condition Large Ensembles

One Global Climate Model



One radiative forcing
pathway



Many simulations



Initial-condition
perturbations

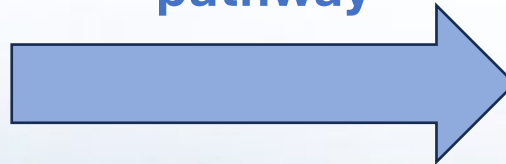


• Initial-condition Large Ensembles

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Many simulations



Initial-condition
perturbations

- A range of mean state outcomes due to internal variability.

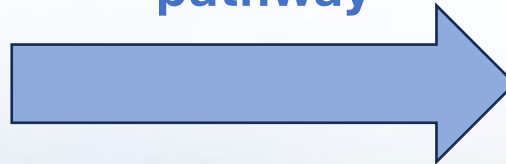


• Initial-condition Large Ensembles

One Global Climate Model



One radiative forcing
pathway



Many simulations



Initial-condition
perturbations

- A range of mean state outcomes due to internal variability.
- Lots of samples of internal variability across the members at each time step.



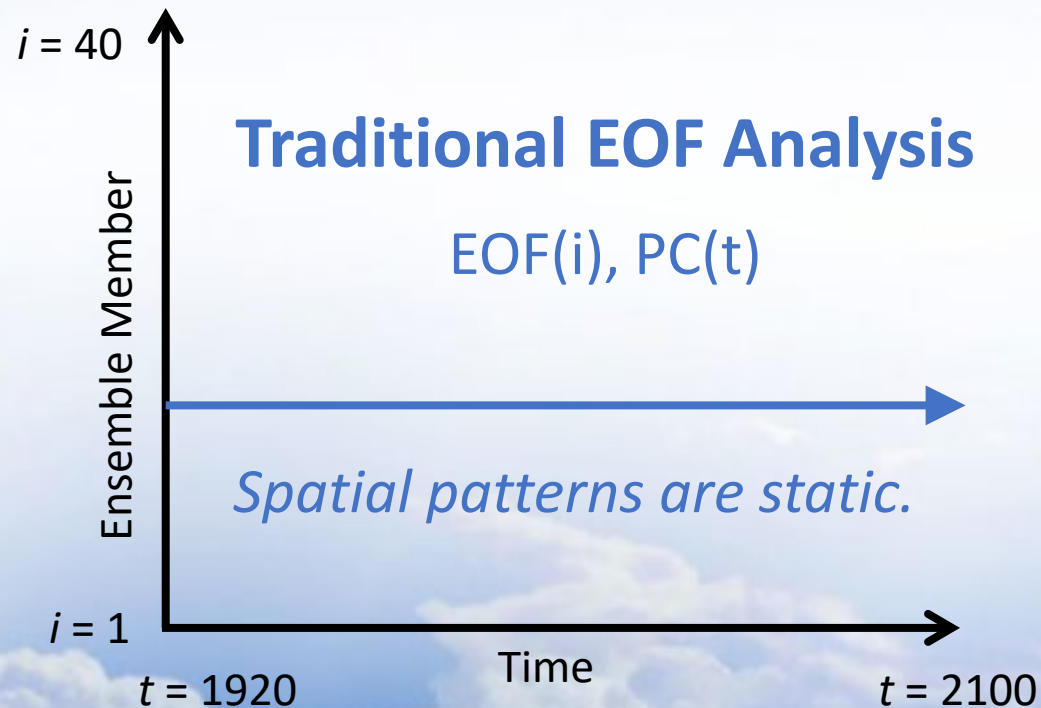
- Initial-condition Large Ensembles
- Snapshot EOF Analysis

**How will the characteristics of internal variability change with climate change?
(spatial patterns, amplitudes, frequency...)**



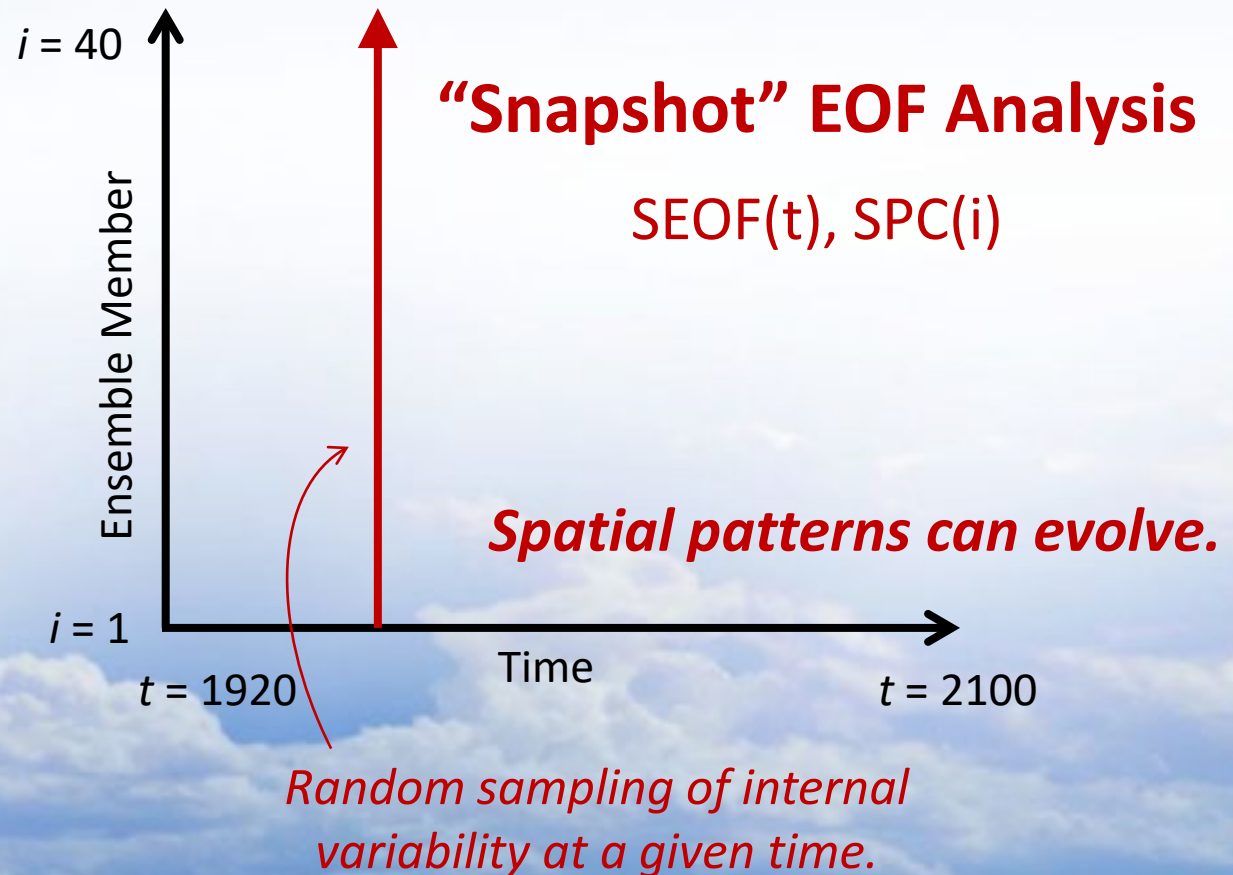


- Initial-condition Large Ensembles
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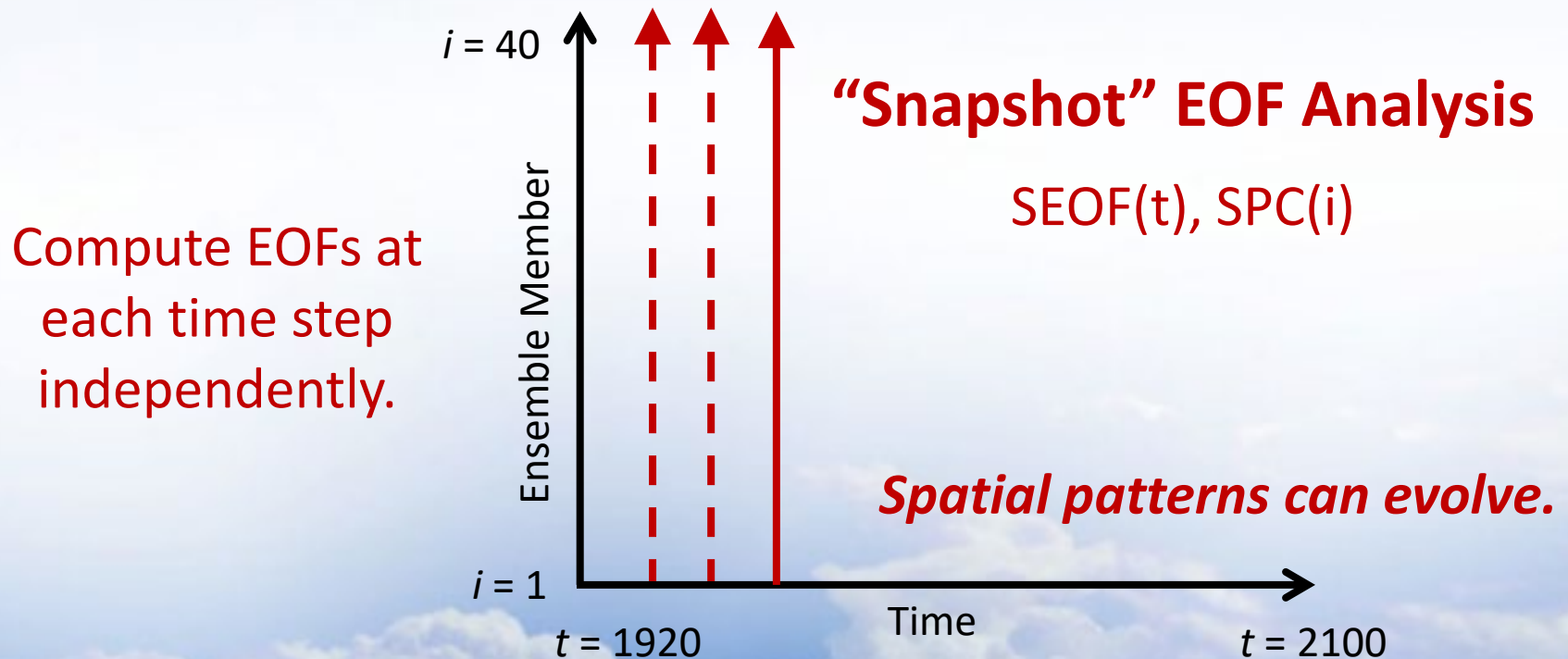


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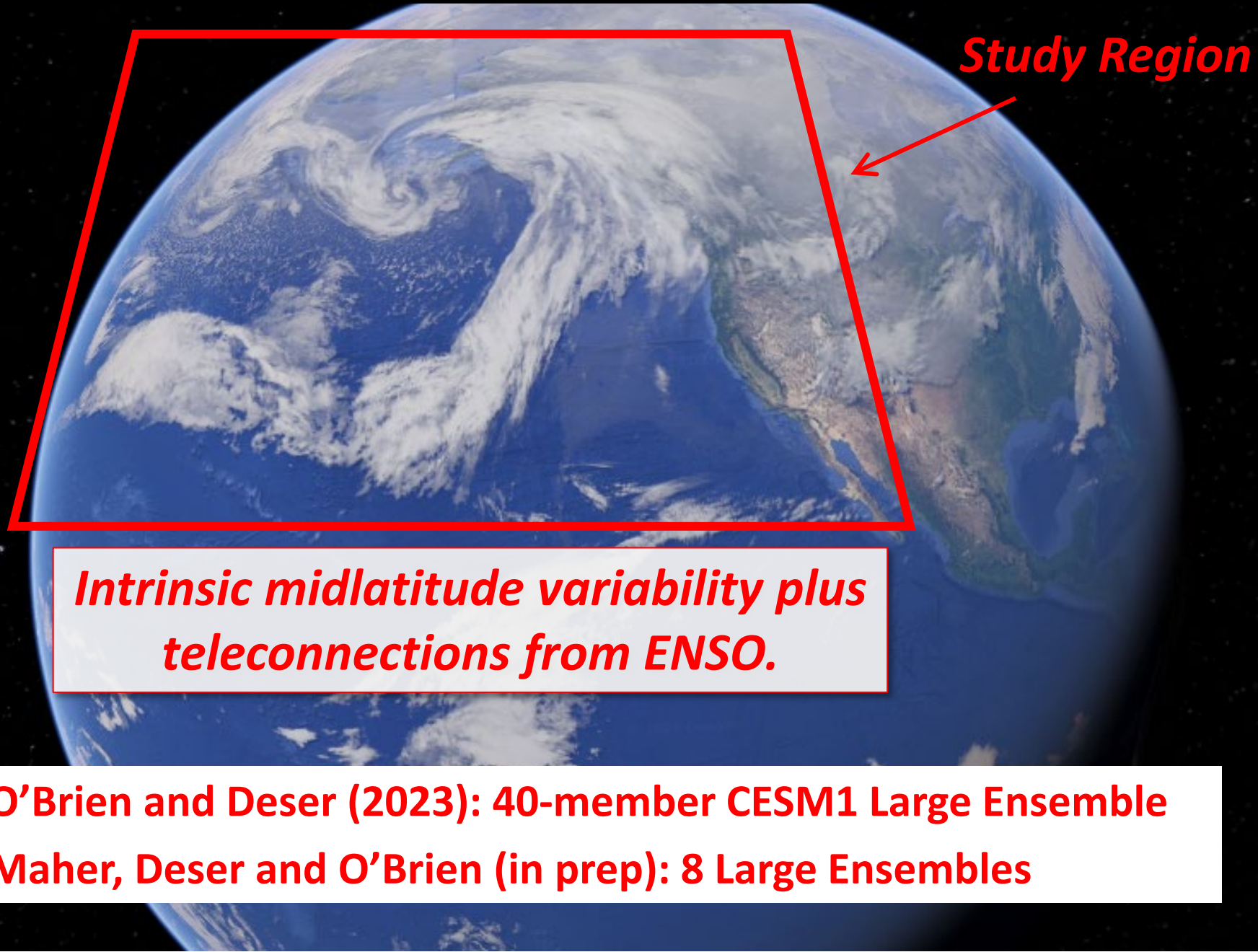


- Initial-condition Large Ensembles
- Snapshot EOF Analysis



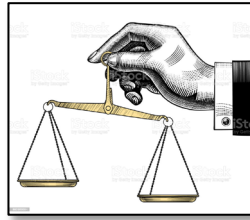
- Provides a direct way to assess evolving forced changes in the leading patterns of internal variability.

Snapshot EOFs Z500 (DJF) 1920-2100 CESM1

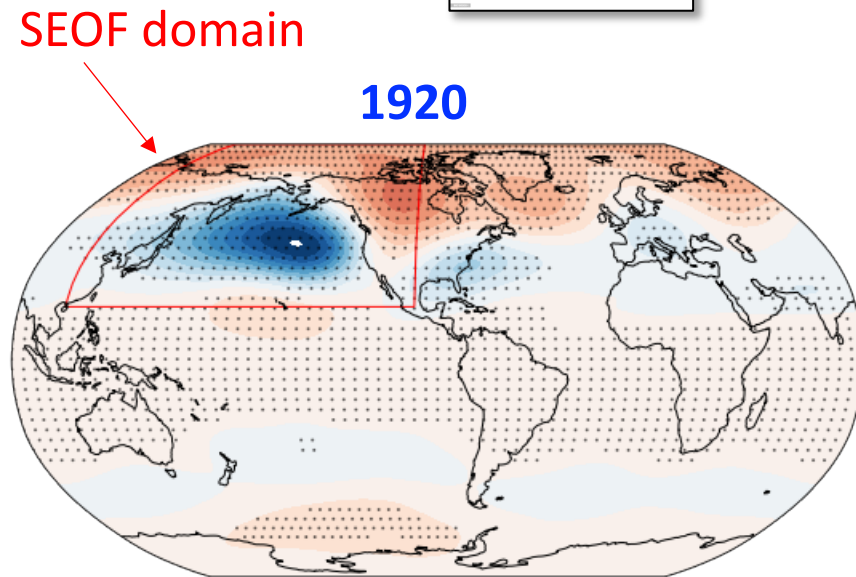


- O'Brien and Deser (2023): 40-member CESM1 Large Ensemble
- Maher, Deser and O'Brien (in prep): 8 Large Ensembles

Leading Mode of North Pacific Z500 Variability (Snapshot EOF1)

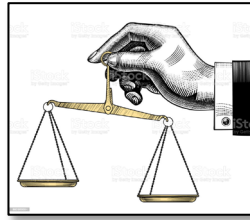


- Z500 regressions onto standardized SPC
- Positive phase shown for convenience
- Stippled areas are 99% significant



"Pacific-North American Pattern"

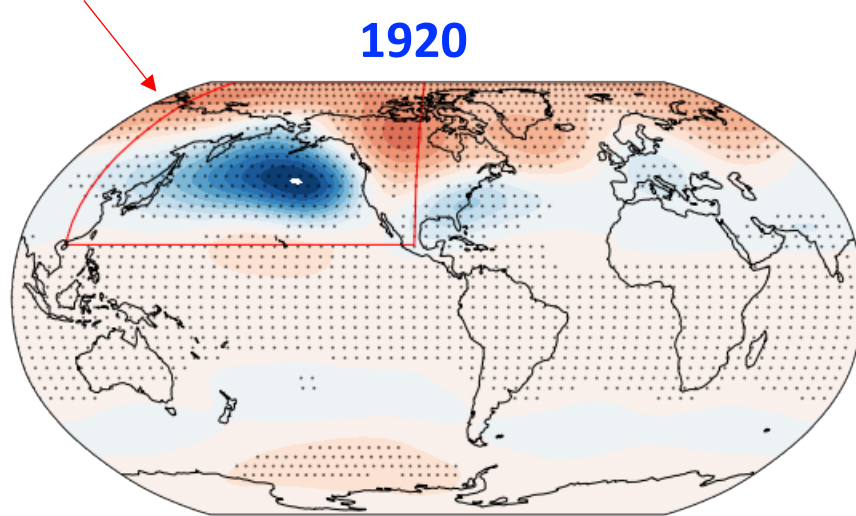
Leading Mode of North Pacific Z500 Variability (Snapshot EOF1)



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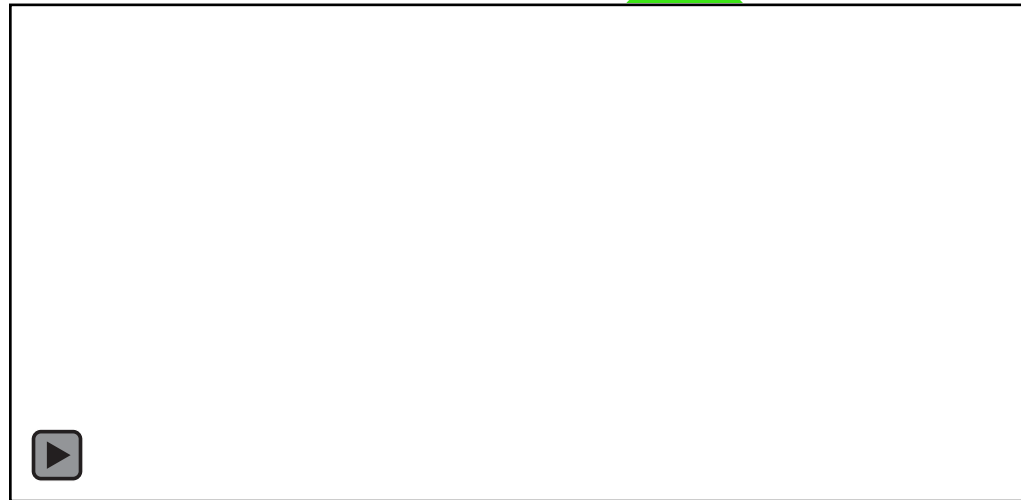
SEOF domain

1920



"Pacific-North American Pattern"

Animation: 1920 to 2100



Leading Mode of North Pacific Z500 Variability (Snapshot EOF1)

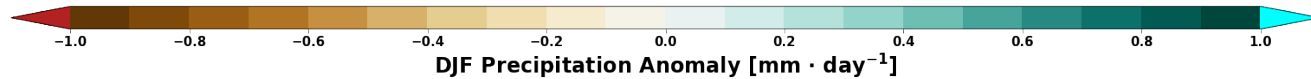
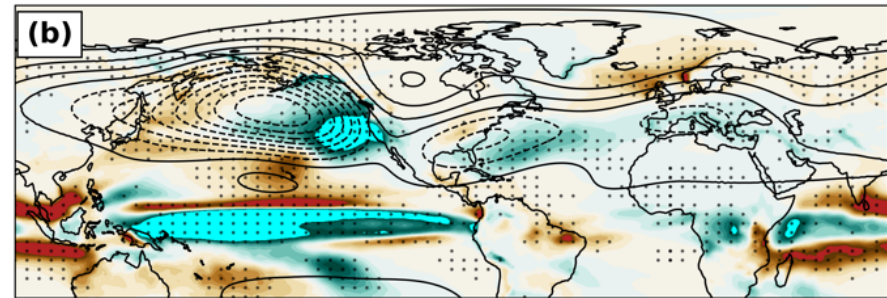
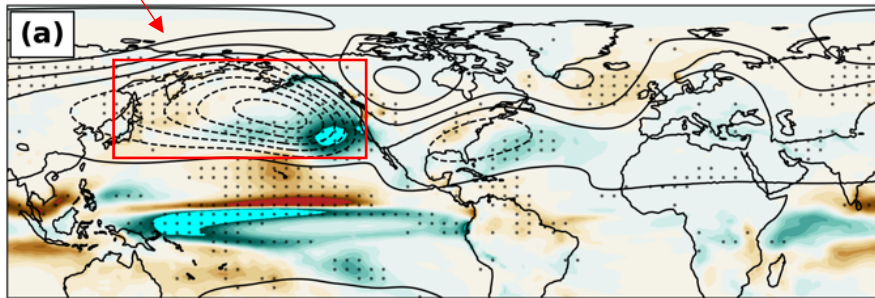
Z500 (contours) and precipitation (shading) regressions; positive phase shown.

SEOF domain

1920



2100



"Pacific-North American Pattern"

Leading Mode of North Pacific Z500 Variability (Snapshot EOF1)

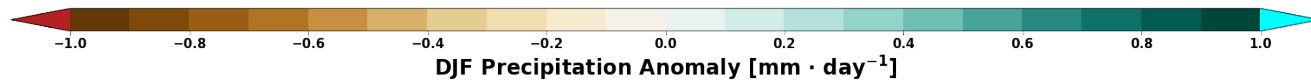
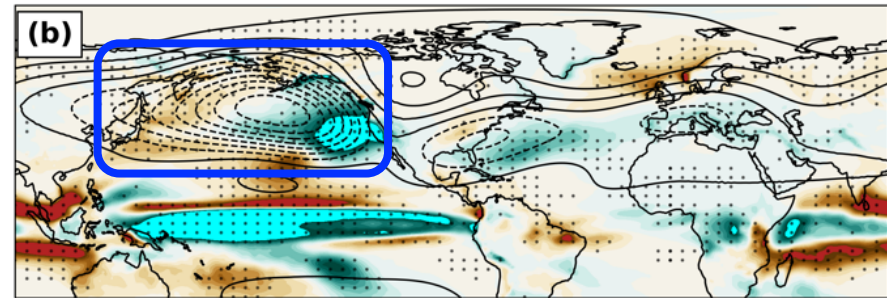
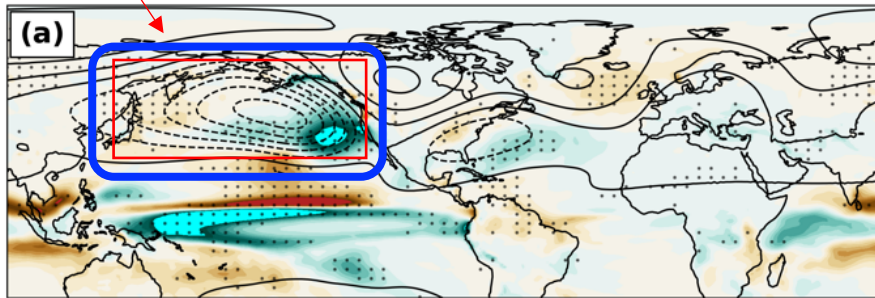
Z500 (contours) and precipitation (shading) regressions; positive phase shown.

SEOF domain

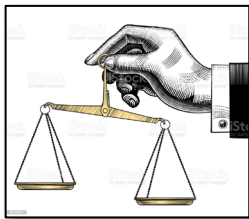
1920



2100



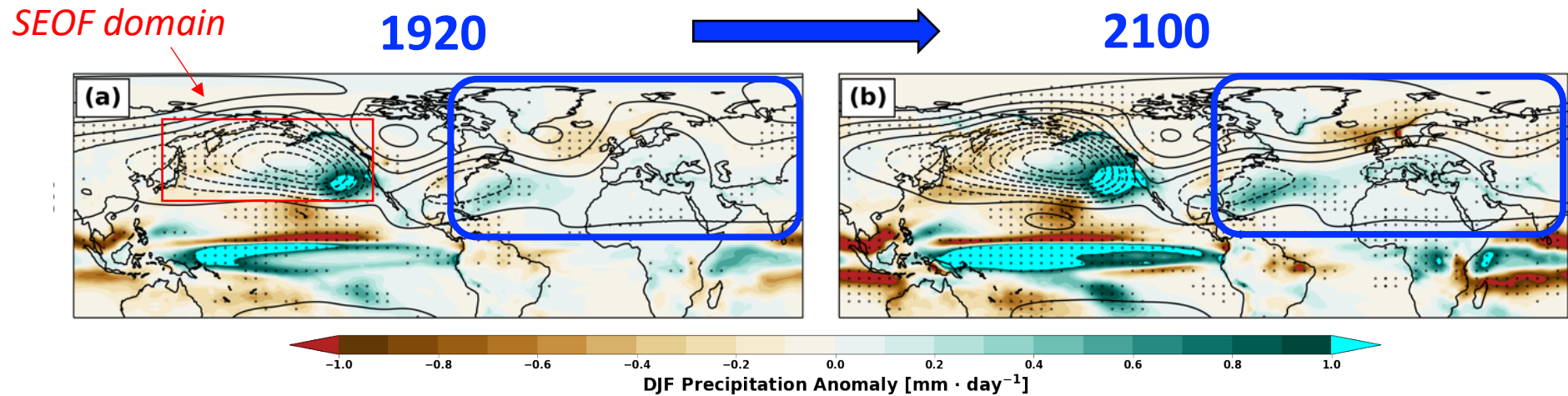
"Pacific-North American Pattern"



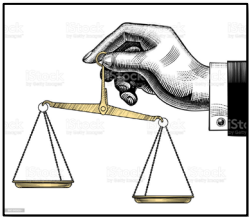
- Intensified Z500 variability and local precipitation impacts.

Leading Mode of North Pacific Z500 Variability (Snapshot EOF1)

Z500 (contours) and precipitation (shading) regressions; positive phase shown.



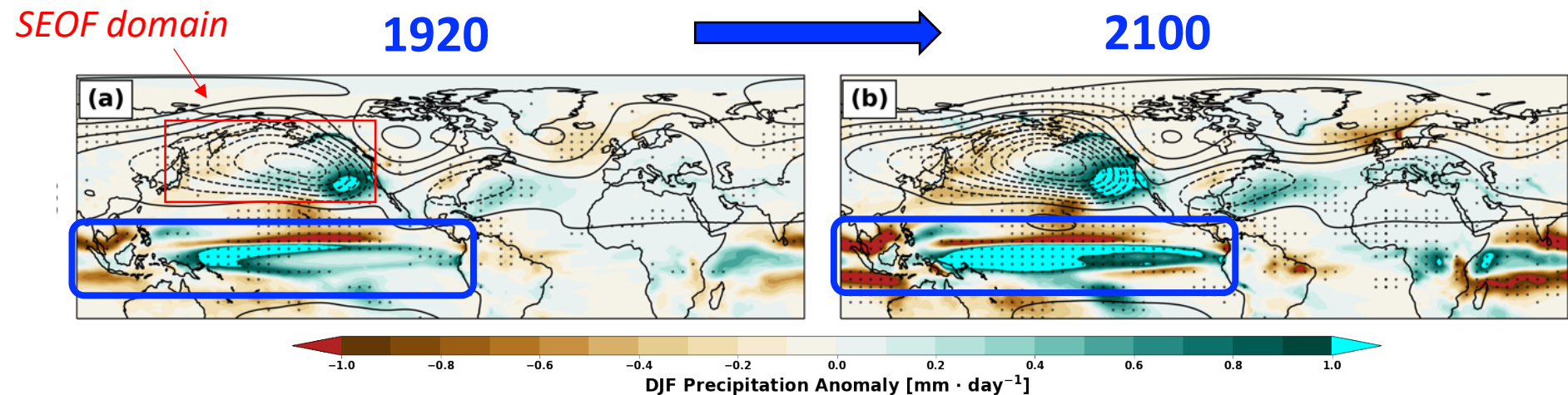
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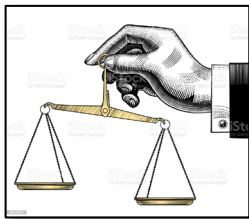
- Intensified Z500 variability and local precipitation impacts.
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Leading Mode of North Pacific Z500 Variability (Snapshot EOF1)

Z500 (contours) and precipitation (shading) regressions; positive phase shown.



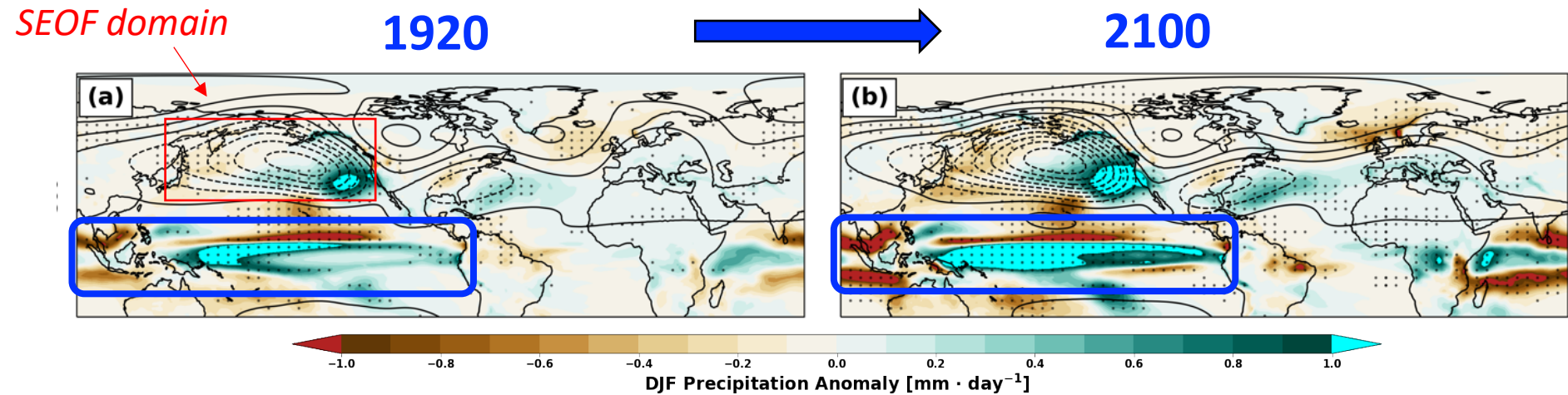
”Pacific-North American Pattern”



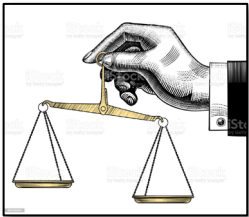
- Intensified Z500 variability and local precipitation impacts.
- Enhanced connection to the North Atlantic.
- Strengthened tropical precipitation linkages.

Leading Mode of North Pacific Z500 Variability (Snapshot EOF1)

Z500 (contours) and precipitation (shading) regressions; positive phase shown.



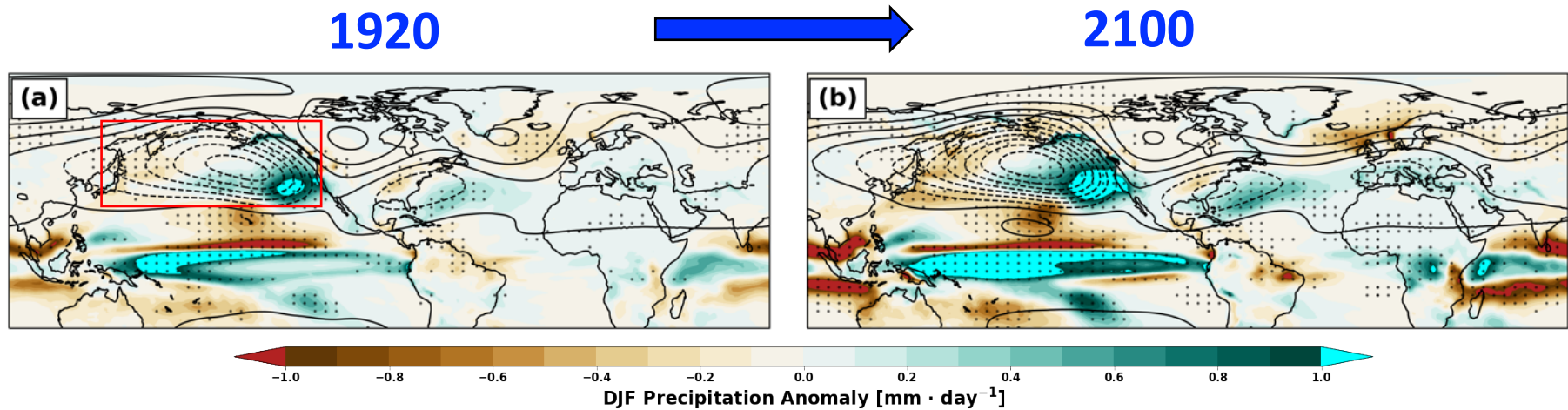
”Pacific-North American Pattern”



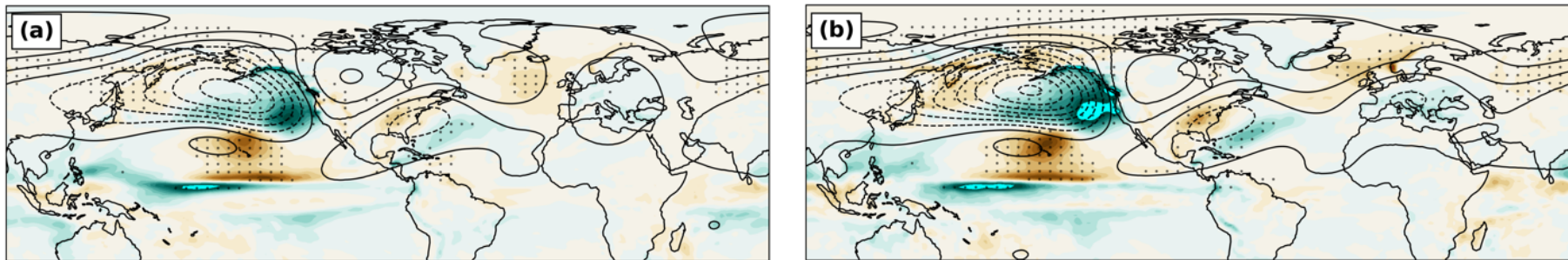
What is the influence of changes in
Tropical Pacific Variability?

Leading Mode of North Pacific Z500 Variability (Snapshot EOF1)

Z500 (contours) and precipitation (shading) regressions; positive phase shown.



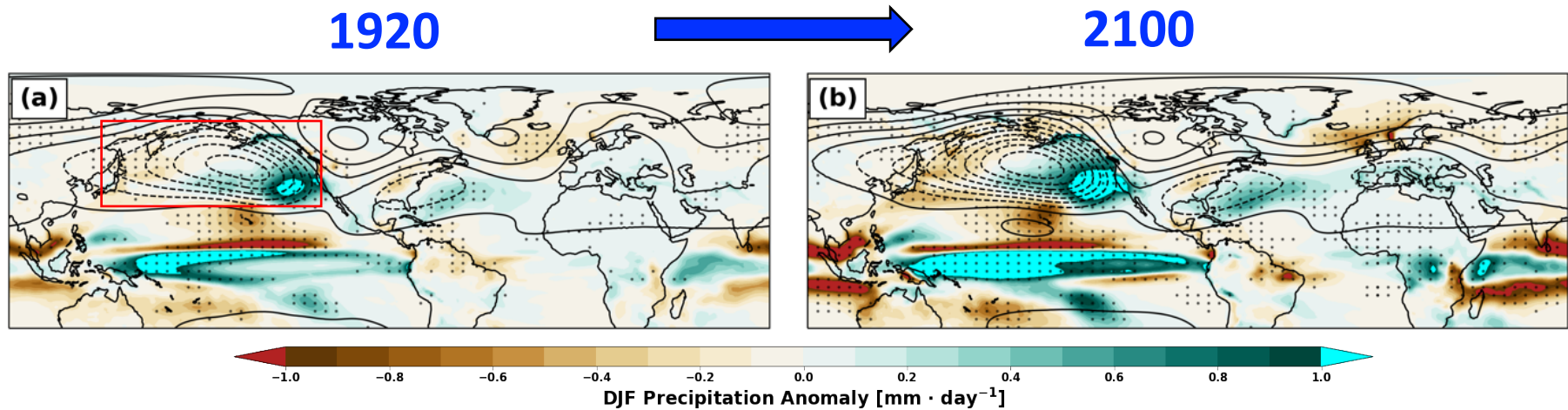
Z500 SEOFs after removing the influence of Tropical Pacific SST SEOFs:



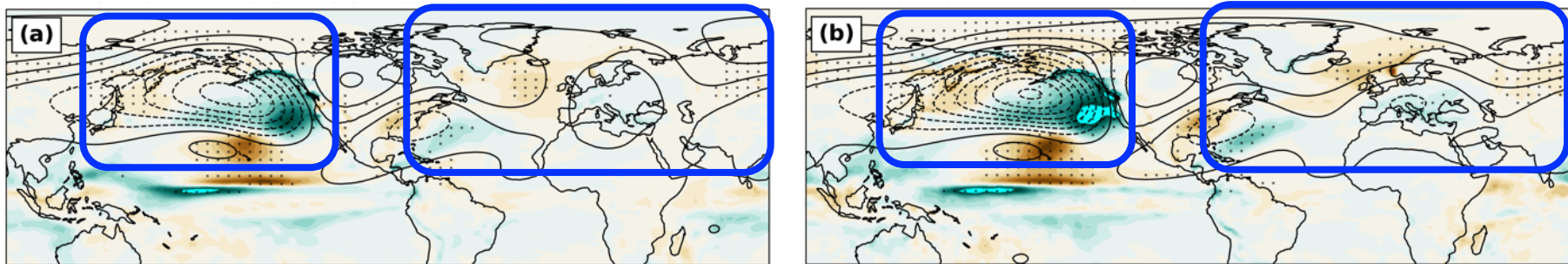
Intrinsic Midlatitude Component of the "Pacific-North American Pattern"

Leading Mode of North Pacific Z500 Variability (Snapshot EOF1)

Z500 (contours) and precipitation (shading) regressions; positive phase shown.



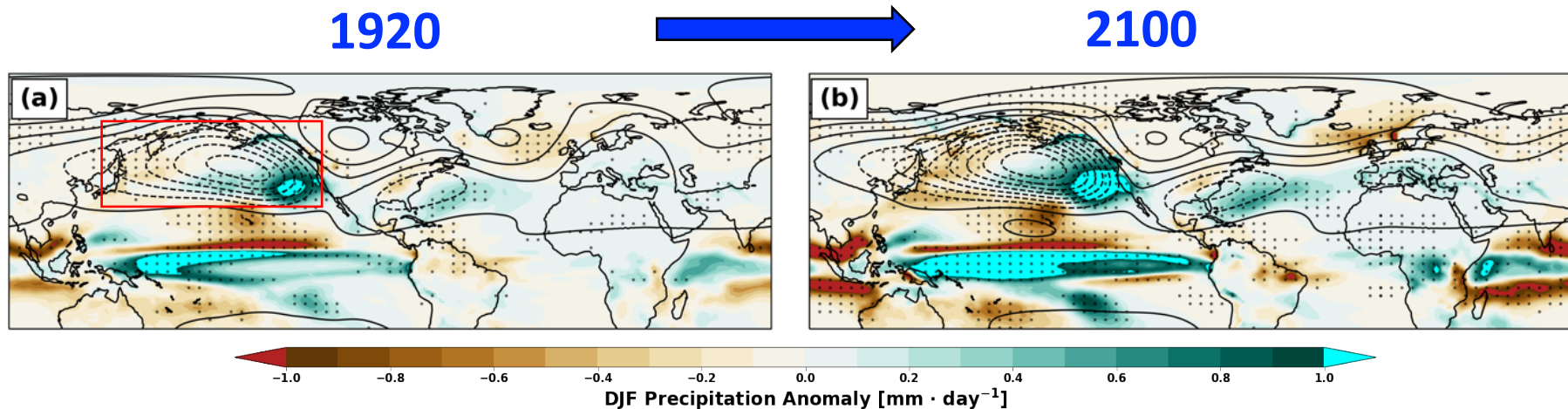
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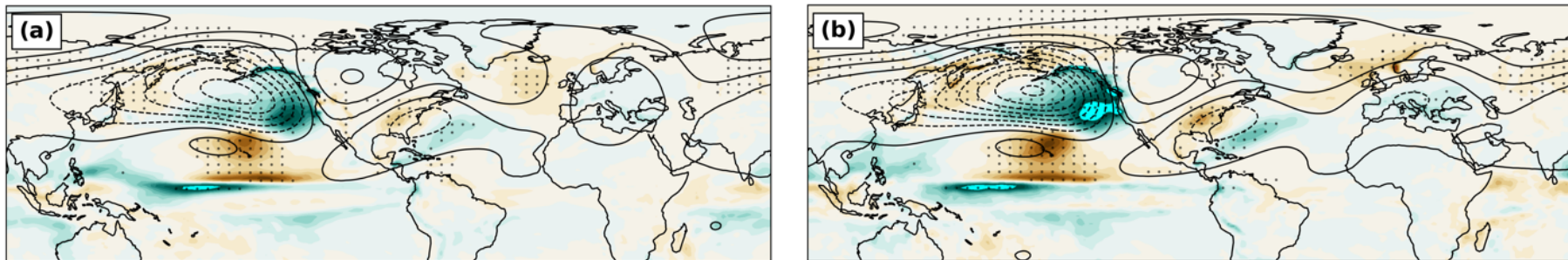
Intrinsic Midlatitude Component of the "Pacific-North American Pattern"

Leading Mode of North Pacific Z500 Variability (Snapshot EOF1)

Strong agreement across 8 Model Large Ensembles that the PNA pattern (SEOF1) will intensify and expand due to changes in both ENSO *and* intrinsic midlatitude dynamics.



Z500 SEOFs after removing the influence of Tropical Pacific SST SEOFs:

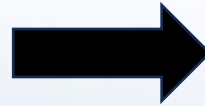


Intrinsic Midlatitude Component of the "Pacific-North American Pattern"

Summary



- Initial-condition Large Ensembles
- Snapshot EOF Analysis

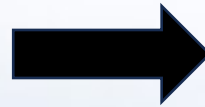


**How will
anthropogenic
forcing alter
modes of climate
variability?**

Summary



- Initial-condition Large Ensembles
- Snapshot EOF Analysis



**How will
anthropogenic
forcing alter
modes of climate
variability?**

- **Multi-model Large Ensemble Archive v2 (Maher et al. 2025)**
18 models + obs, regridded to a common 2.5x2.5° grid, 15 variables.
www.cesm.ucar.edu/community-projects/mmlea/v2
- **Updated Climate Variability Diagnostics Package v6**