A Robust Null Hypothesis for the Role of the Tropical Pacific in Driving Megadrought in Western North America

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Scott St. George
Sloan Coats
Jason Smerdon

Is the record of megadrought in western North America consistent with the linearly-forced, stochastically-damped paradigm?

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Yes.

Is the record of megadrought in western North America consistent with the linearly-forced, stochastically-damped paradigm?

Yes.
No.

Is the record of megadrought in western North America consistent with the linearly-forced, stochastically-damped paradigm?

Yes.

No.

Maybe…

Paleoclimate Data vs. Global Climate Models

What do we agree on?

(1) Megadroughts have happened.
(2) ENSO has a major influence on drought in Western North America (WNA).
(3) Late 20th century is "well observed."

What do we agree on?

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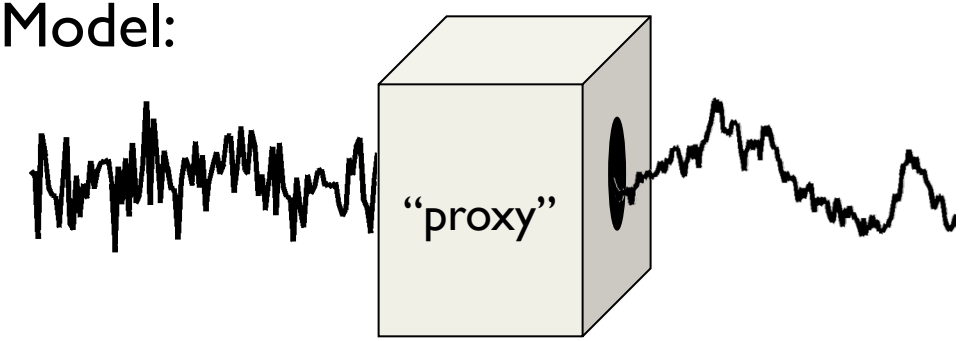
→ **We assume:** different combinations of internal modes would be possible without changes to the boundary conditions.

What should we expect?

AR(1) Model:

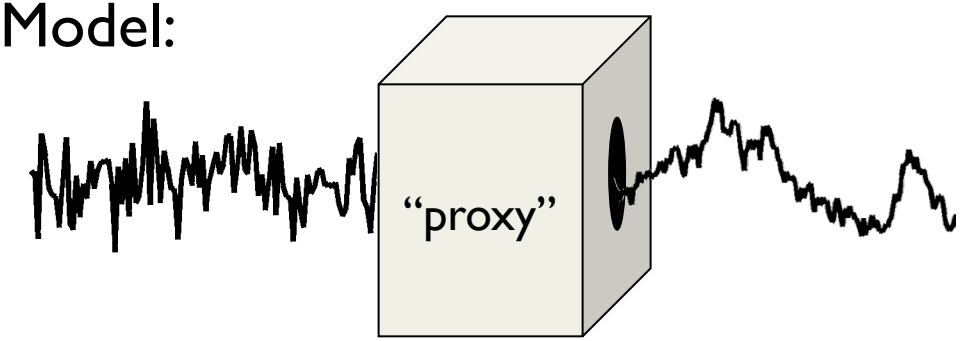


$$\frac{dx_t}{dt} = \rho x_{t-1} + \eta$$

Noise

Autocorrelation

AR(1) Model:



$$\frac{dx_t}{dt} = \rho x_{t-1} + \eta$$

No role for ENSO
No spatial "structure"

We want

- Test stochastically-forced, linearly damped paradigm (Hasslemann)
- But, accommodate:
  ENSO
  Spatially-correlated "noise"
  Autcorrelation

Linear Inverse Model (LIM)

State Vector

$$\frac{d\tilde{\mathbf{x}}}{dt} = [\mathbf{L}]\tilde{\mathbf{x}} + \eta$$

[ ] = matrix

Linear Inverse Model (LIM)

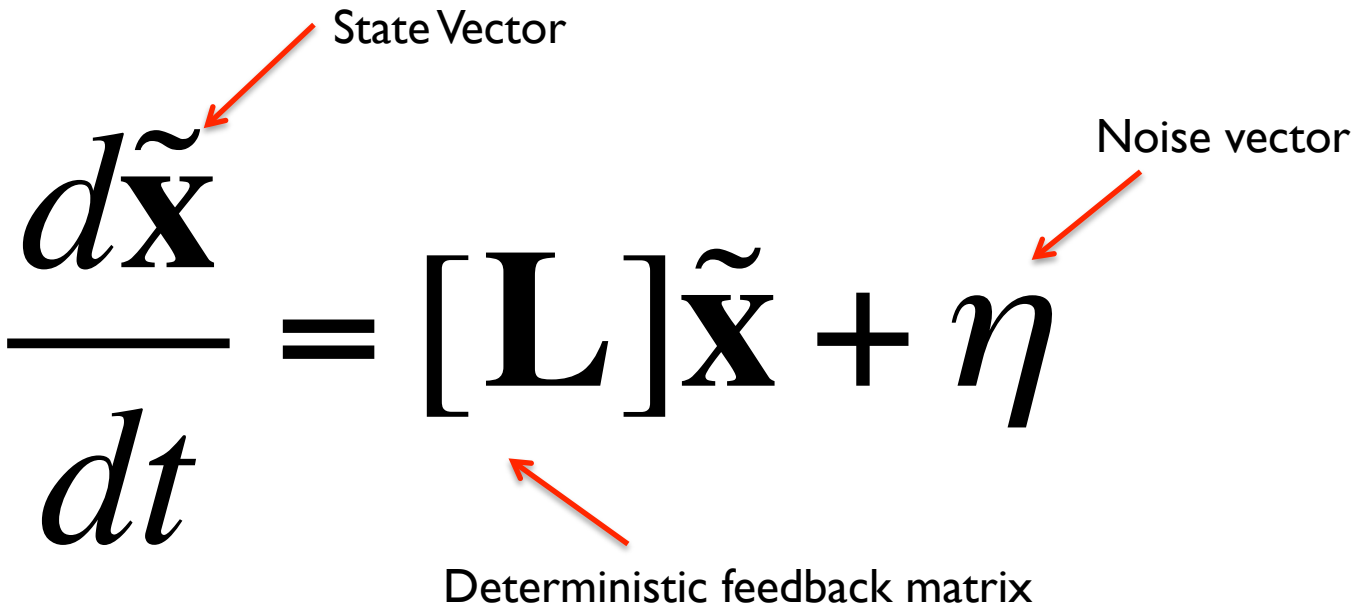
State Vector

$$\frac{d\tilde{\mathbf{x}}}{dt} = [\mathbf{L}]\tilde{\mathbf{x}} + \eta$$

Deterministic feedback matrix

[ ] = matrix

Linear Inverse Model (LIM)



[ ] = matrix

How has the LIM been applied?

$$\frac{d\tilde{\mathbf{x}}}{dt} = [\mathbf{L}]\tilde{\mathbf{x}} + \eta$$

- Seasonal prediction
- ENSO Flavors
- Decadal Prediction
- PDO Diagnostics
- Ocean-Atmosphere coupling
- Dec-Cen tropical Pacific climate variability

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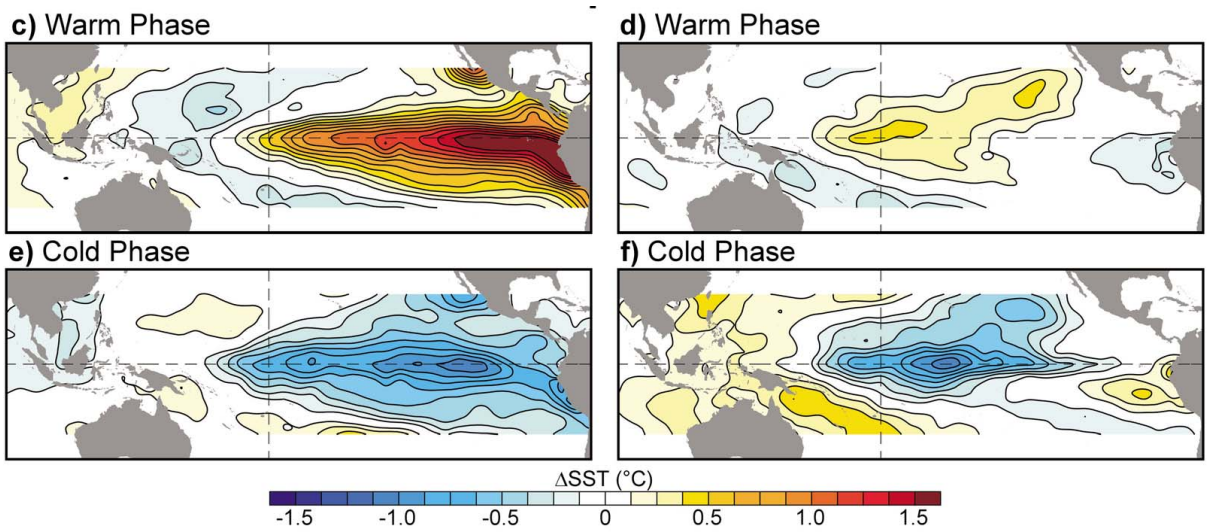

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Newman et al., 2011 (GRL)

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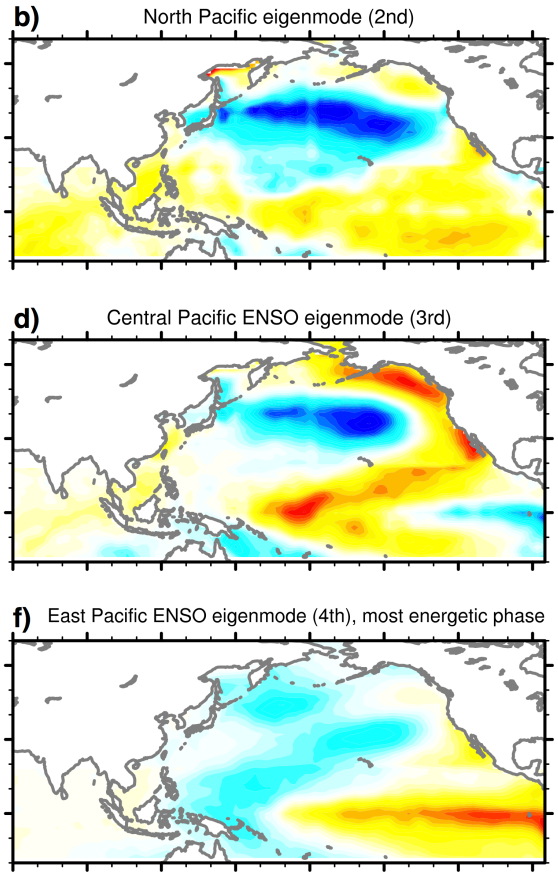

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From "The Pacific decadal oscillation, revisited" Newman et al., 2016 (JCLIM)

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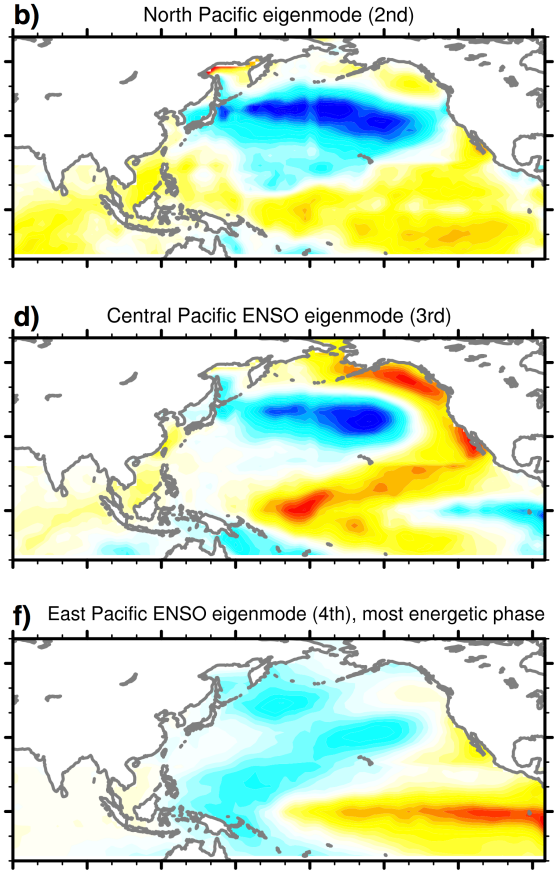

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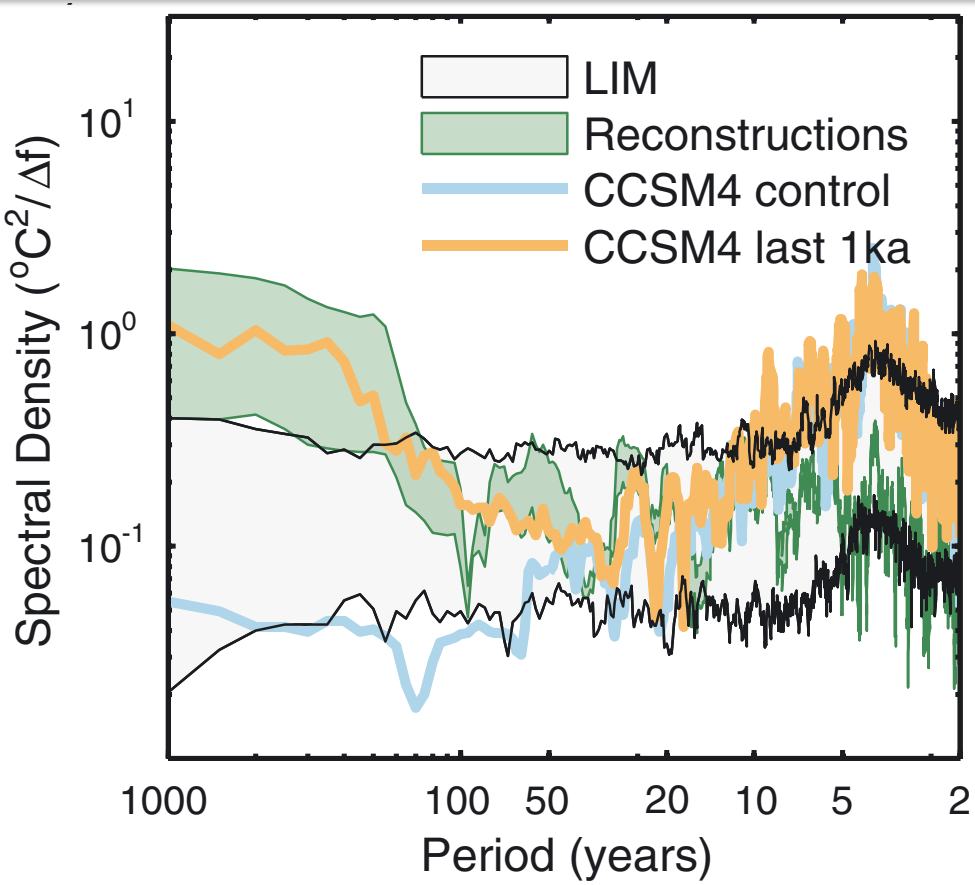

From Ault et al., 2013 (GRL)

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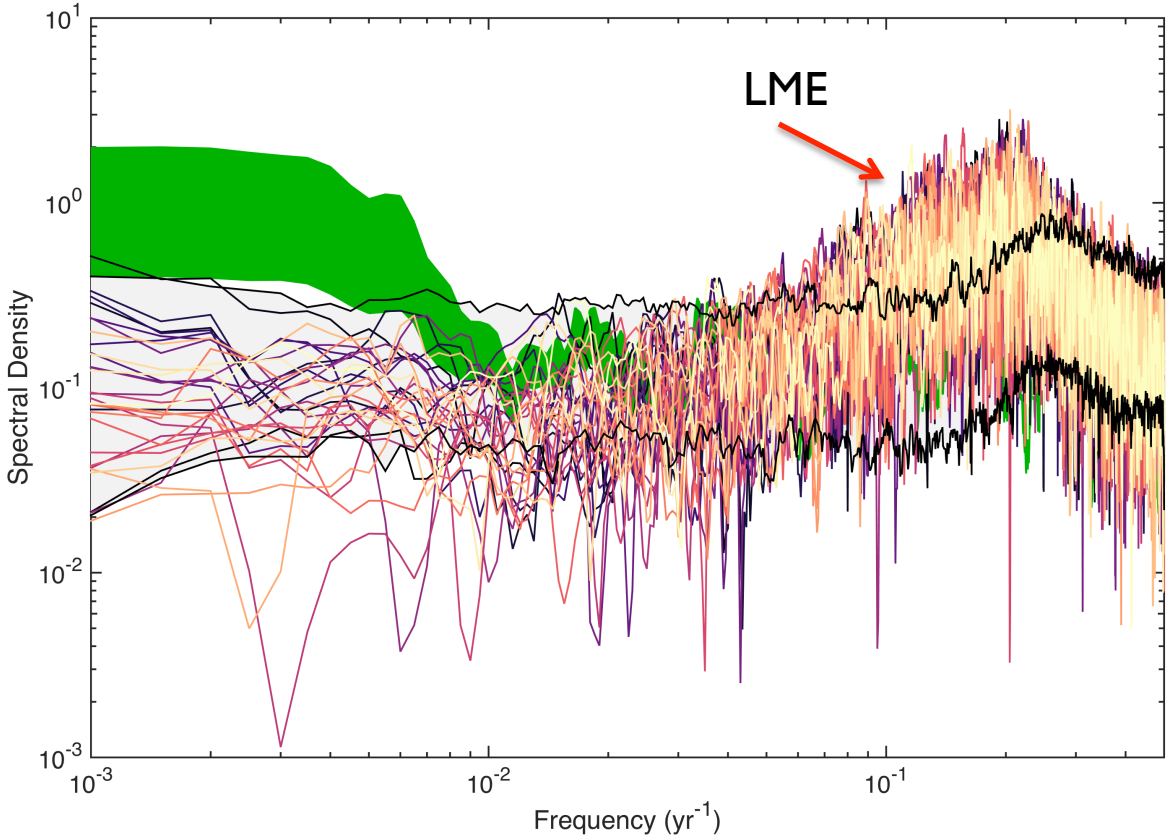

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- ENSO Flavors
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From Ault et al., 2016 (Pages2K conference at Lamont)

Defining the state vector

$$\frac{d\tilde{\mathbf{x}}}{dt} = [\mathbf{L}]\tilde{\mathbf{x}} + \eta$$

Defining the state vector

$$\tilde{\mathbf{x}} = \begin{bmatrix} \text{SST} \\ \tau_x \\ \text{SSH} \\ \text{scPDSI} \end{bmatrix}$$

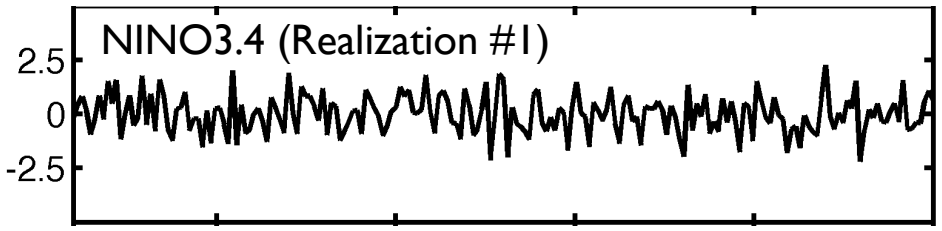
17 PCs (~90% of variance)

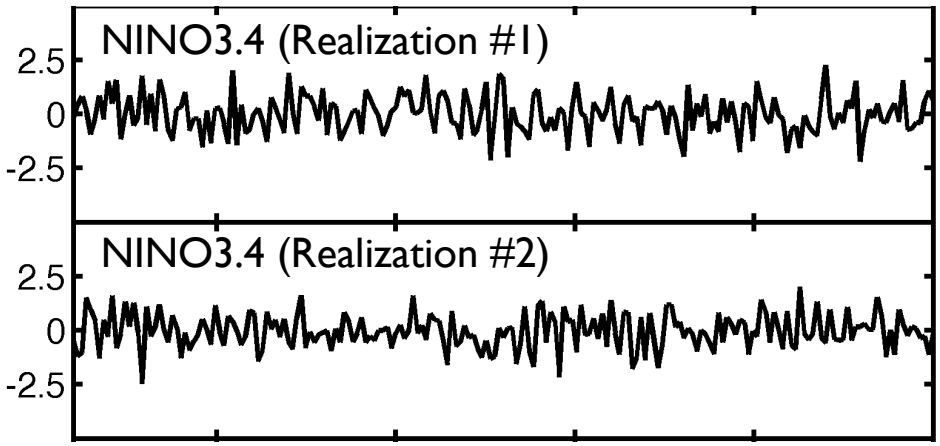
13 PCs (~80% of variance)

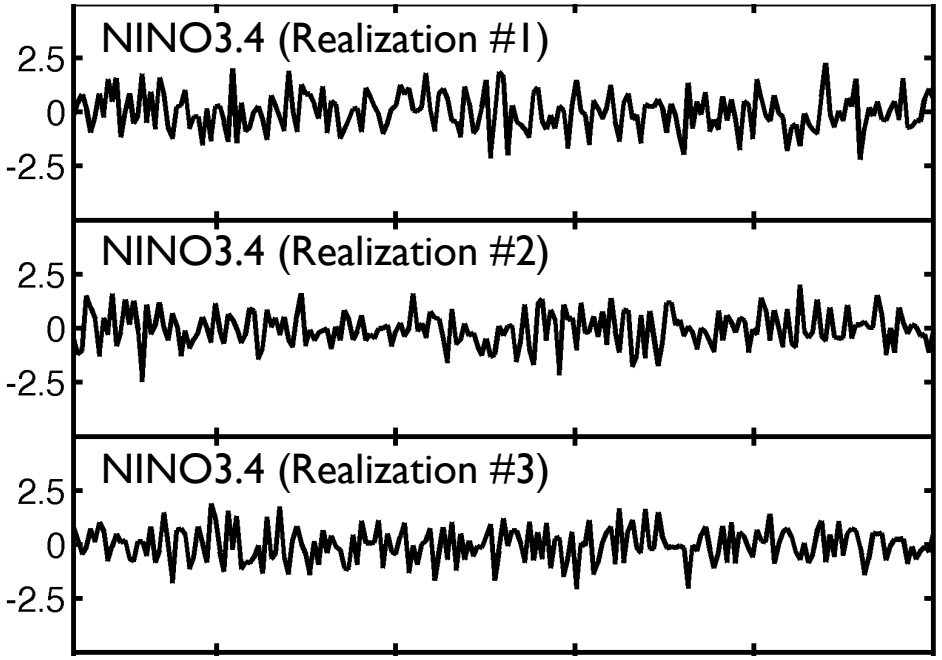
7 Pcs (~50% of variance)

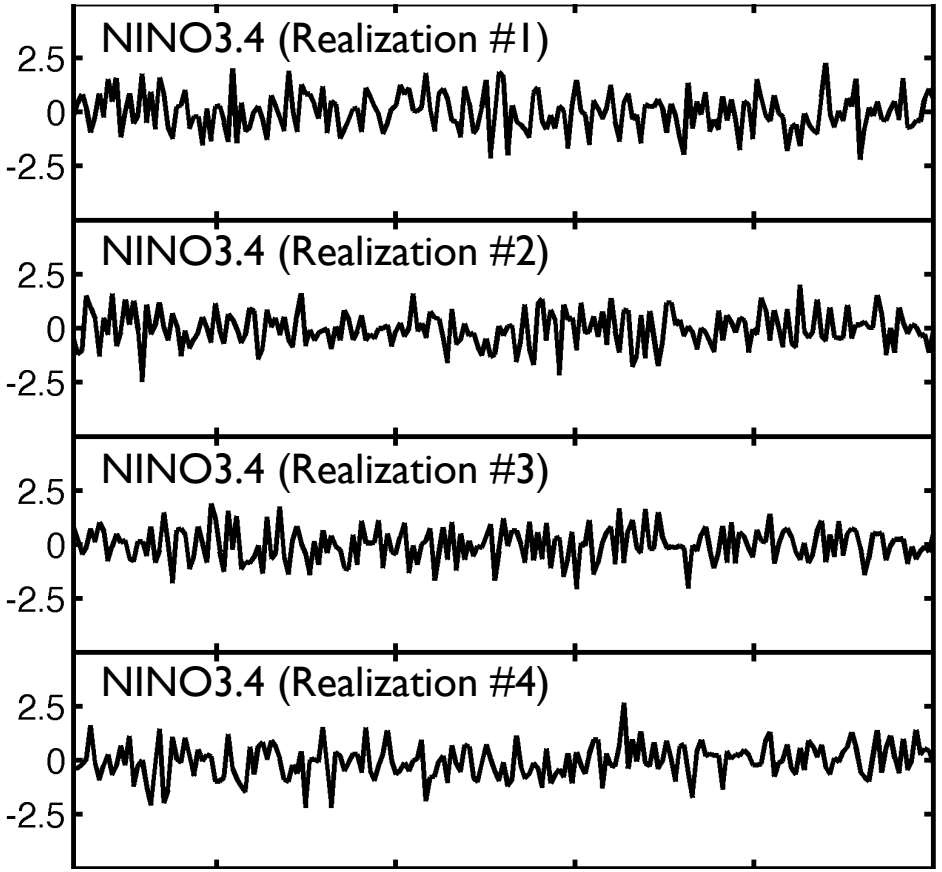
23 Pcs (90% of variance)

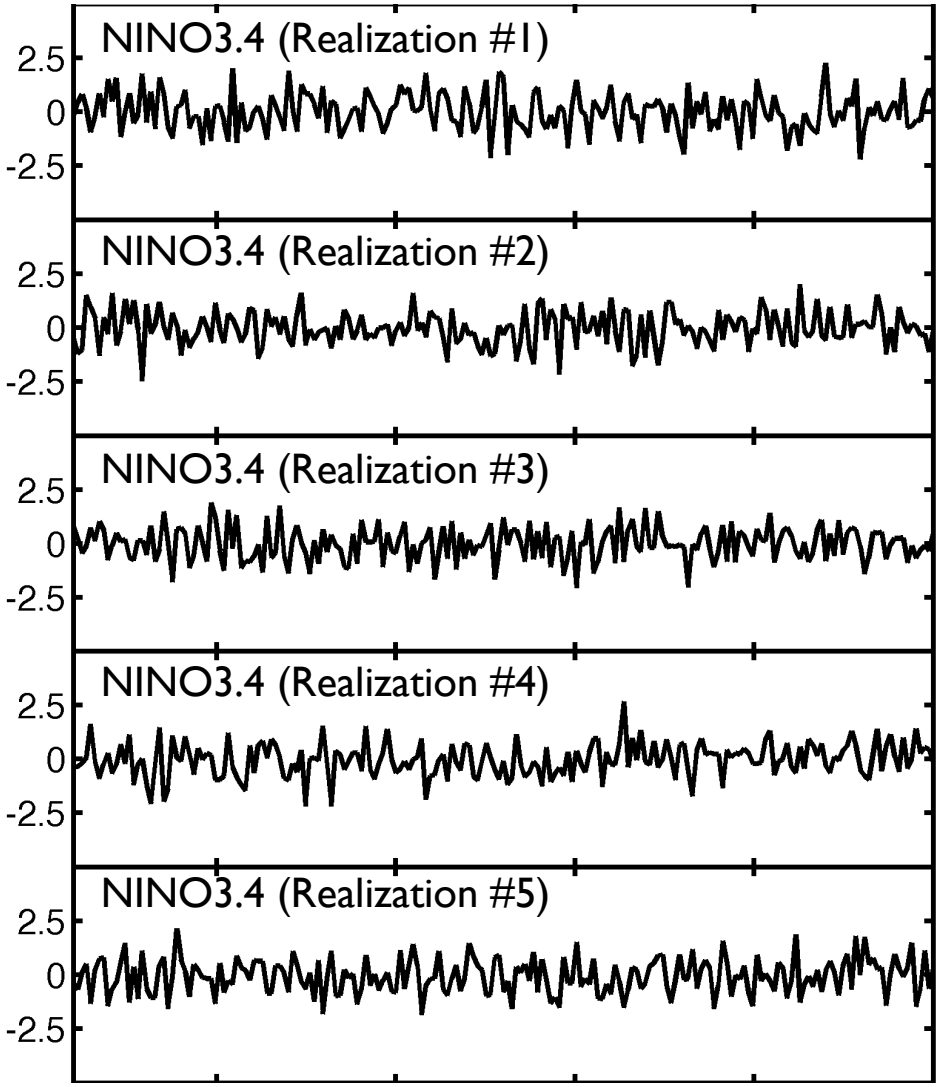
(Low order model of dynamics, Empirically based)


NINO3.4 (Realization #1)
2.5
0
-2.5

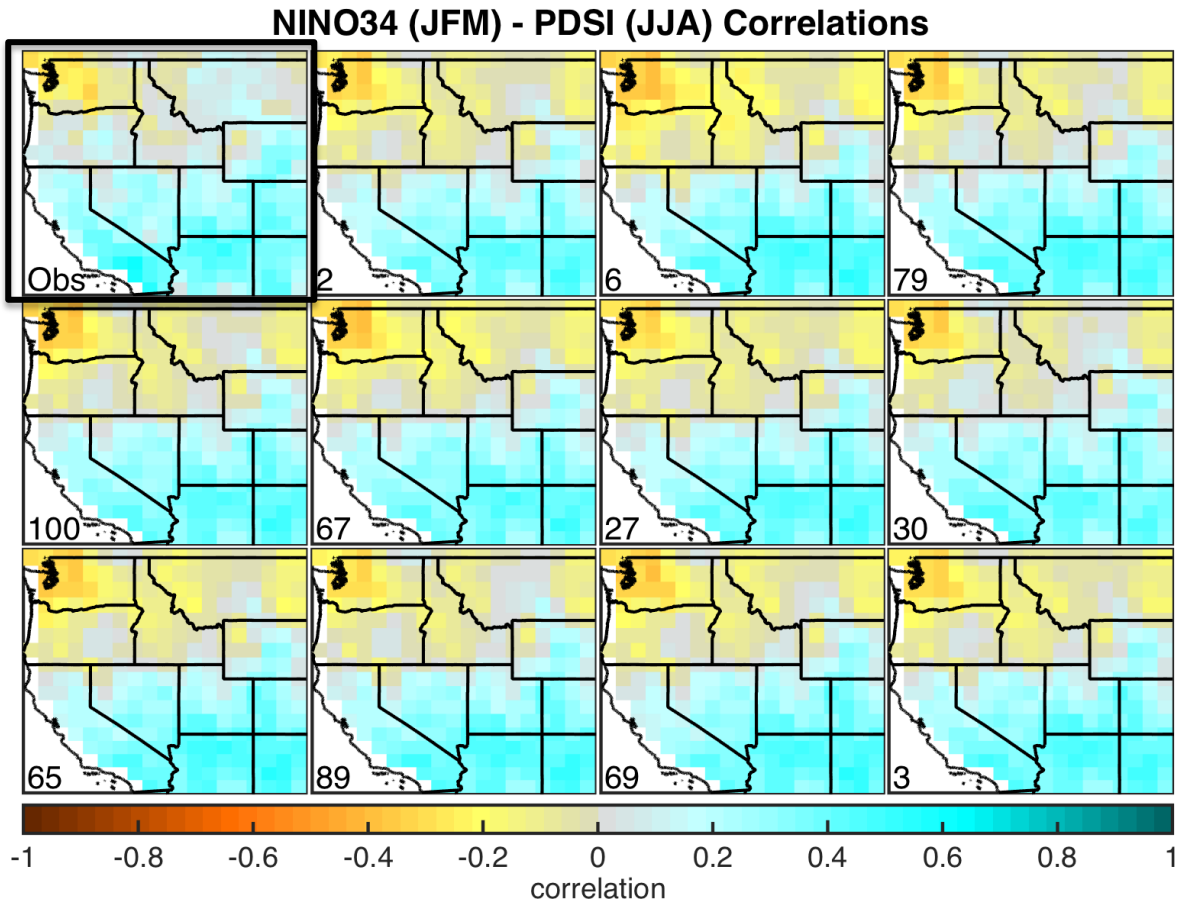

NINO3.4 (Realization #1)
2.5
0
-2.5
NINO3.4 (Realization #2)
2.5
0
-2.5


NINO3.4 (Realization #1)
2.5
0
-2.5
NINO3.4 (Realization #2)
2.5
0
-2.5
NINO3.4 (Realization #3)
2.5
0
-2.5


NINO3.4 (Realization #1)
2.5
0
-2.5
NINO3.4 (Realization #2)
2.5
0
-2.5
NINO3.4 (Realization #3)
2.5
0
-2.5
NINO3.4 (Realization #4)
2.5
0
-2.5


NINO3.4 (Realization #1)
NINO3.4 (Realization #2)
NINO3.4 (Realization #3)
NINO3.4 (Realization #4)
NINO3.4 (Realization #5)
2.5
0
-2.5

Consistency with observations



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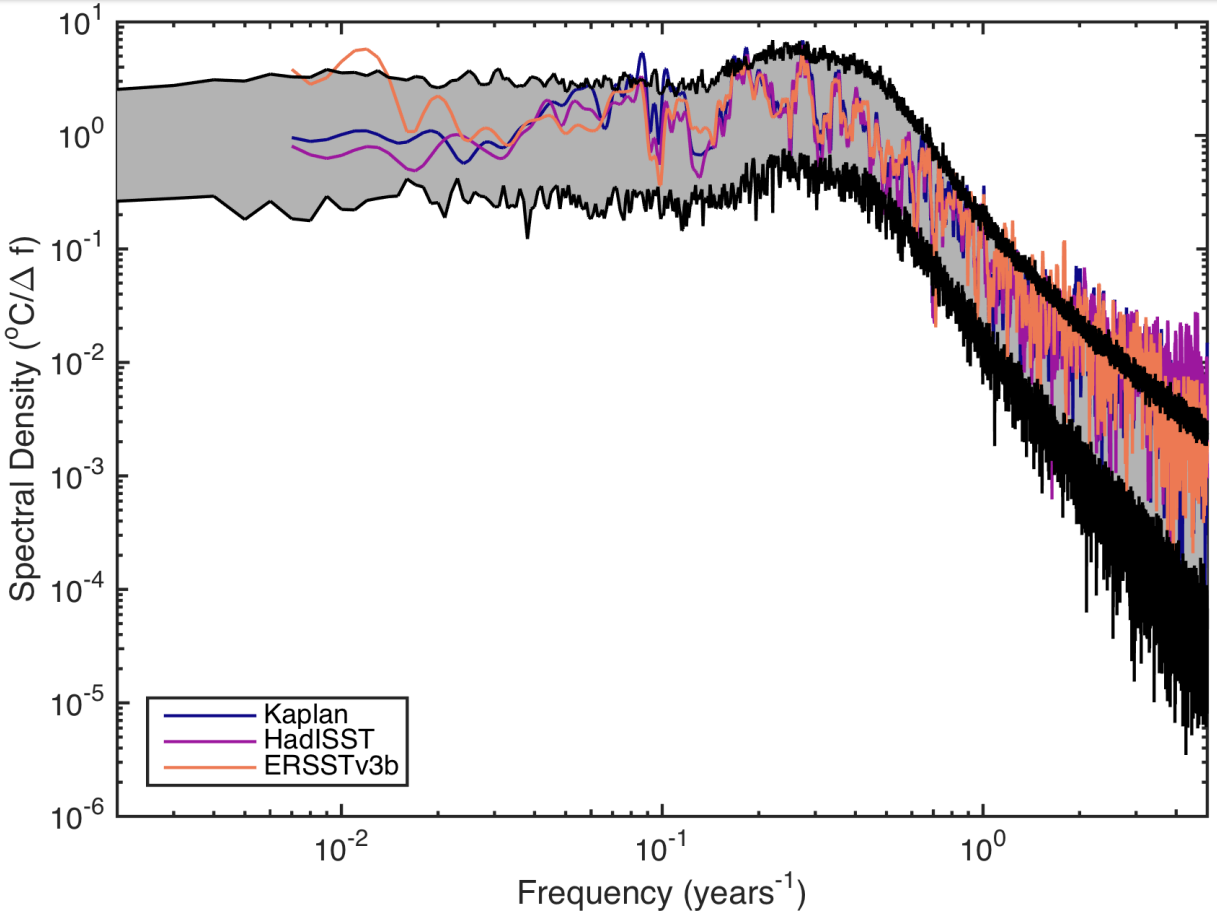
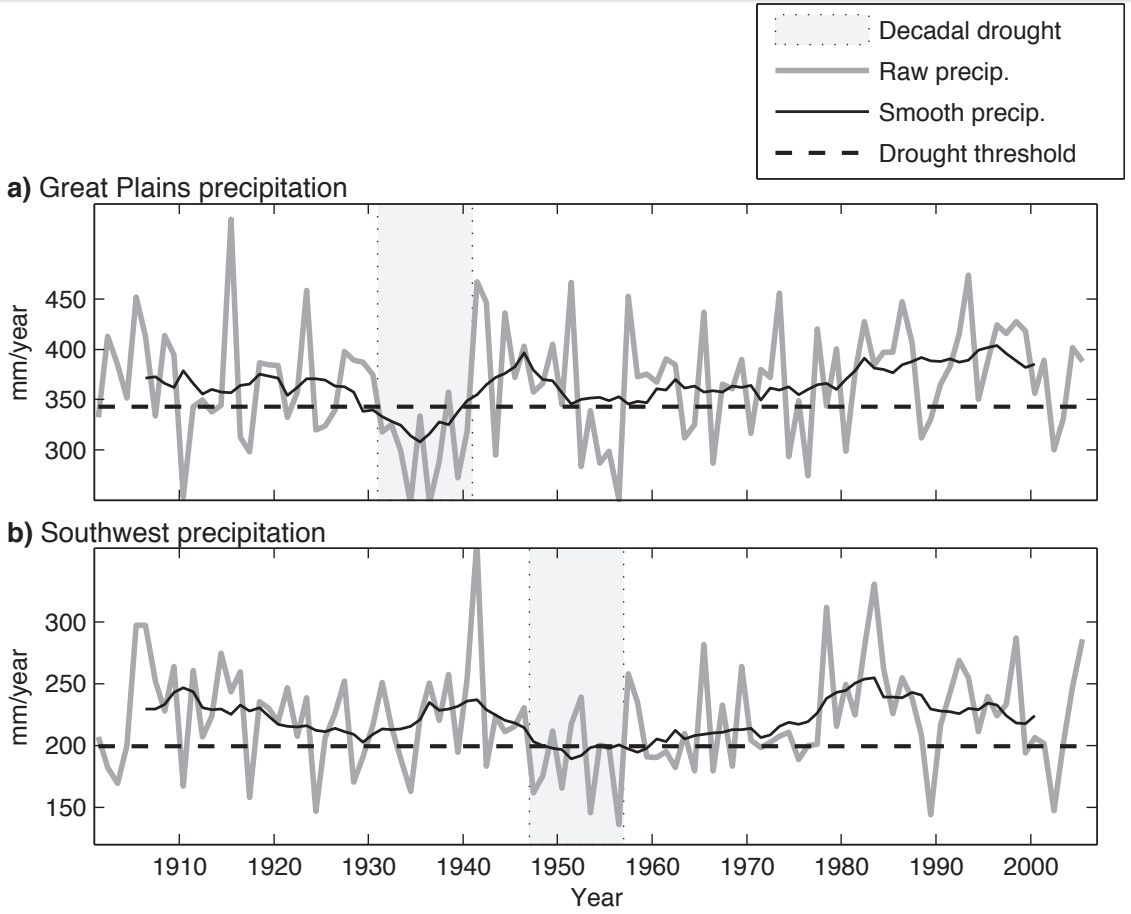
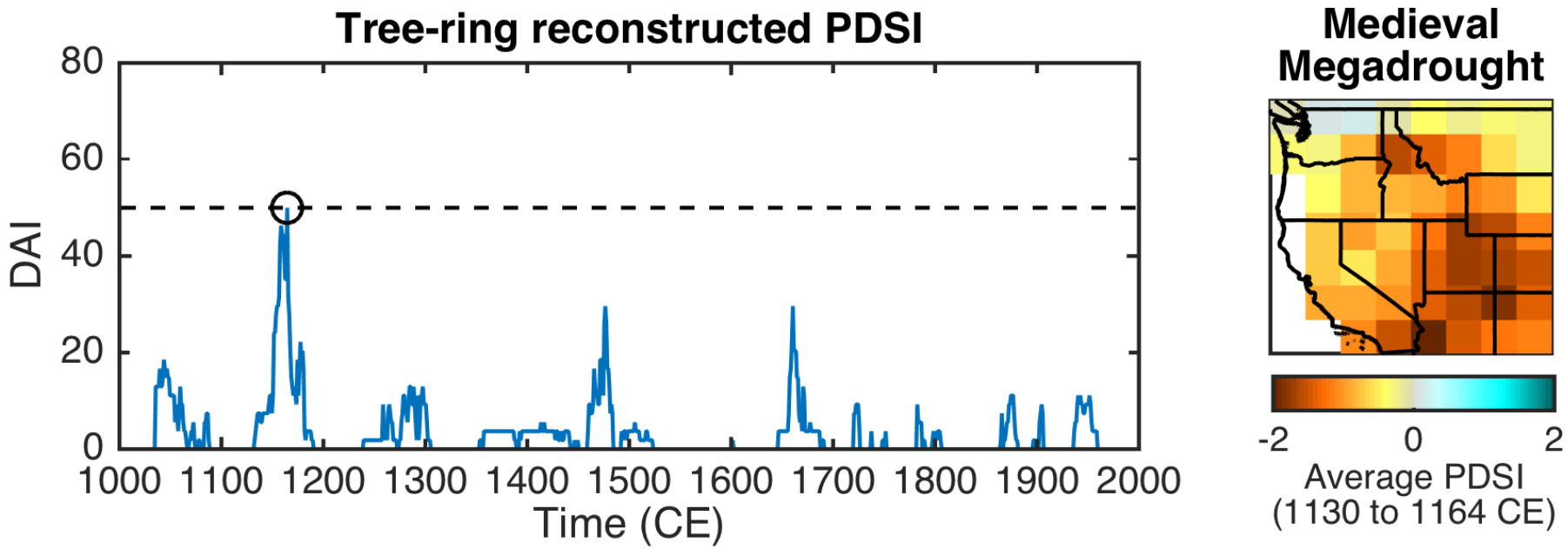
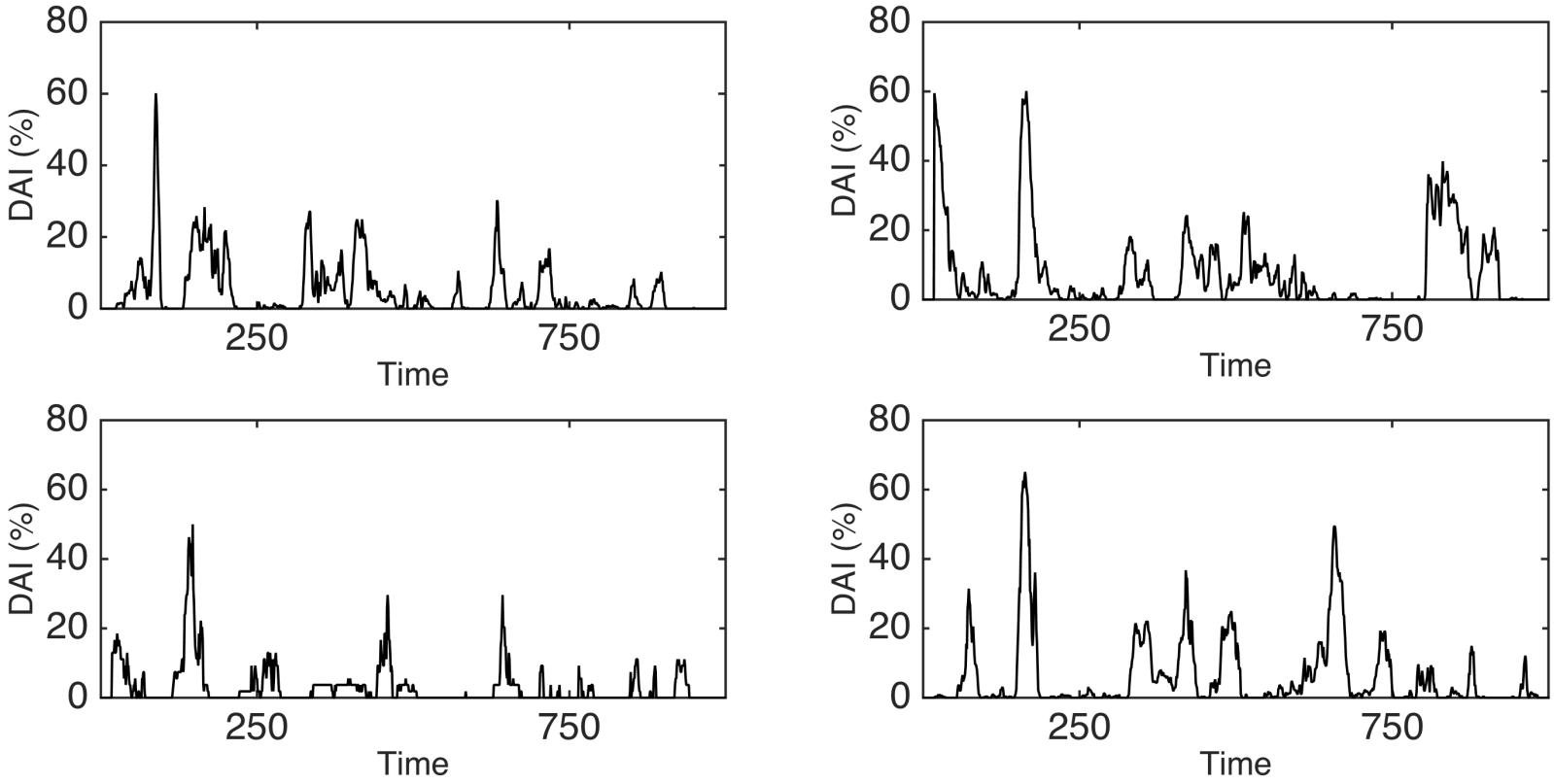


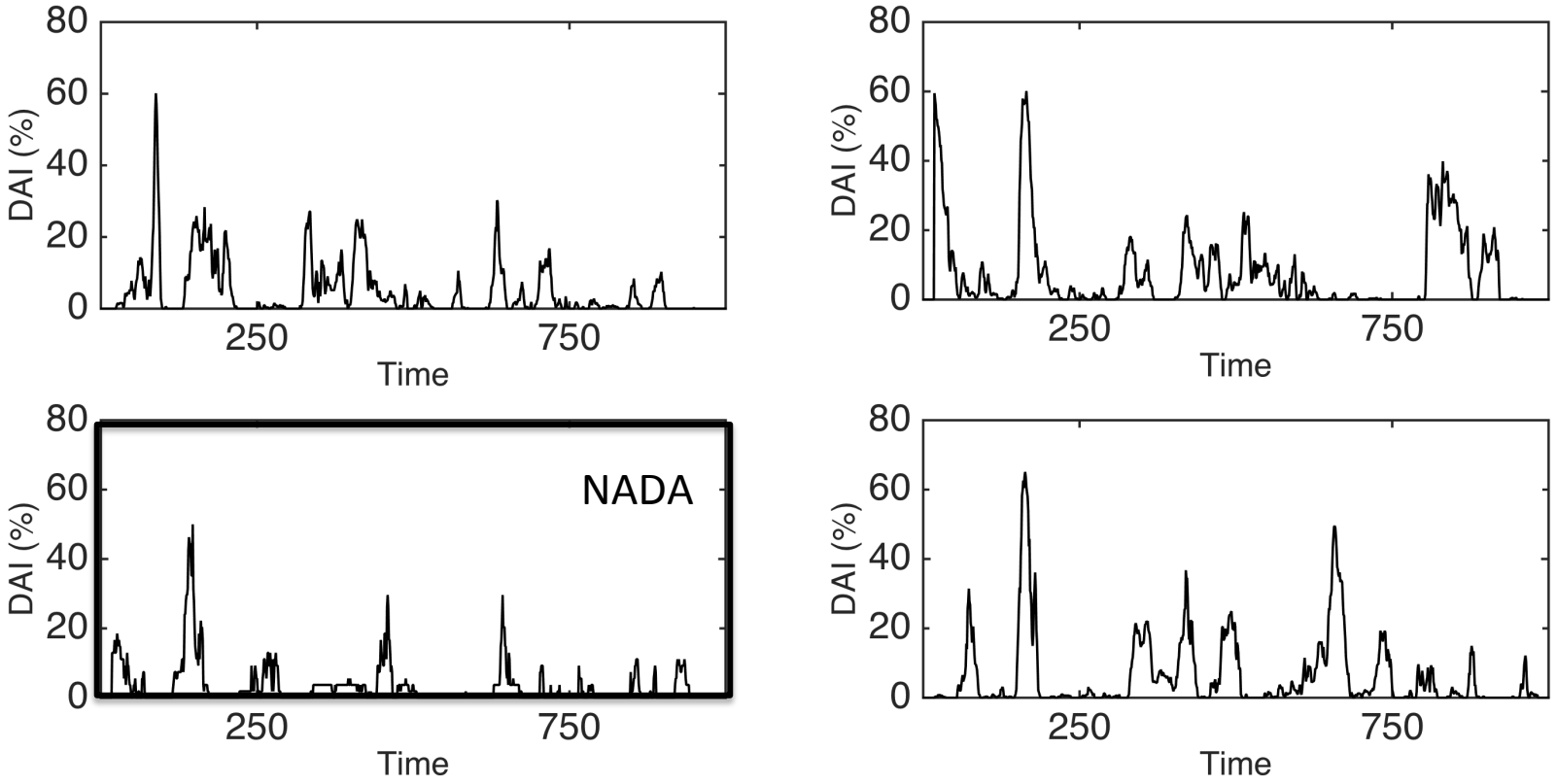
Definition of megadrought

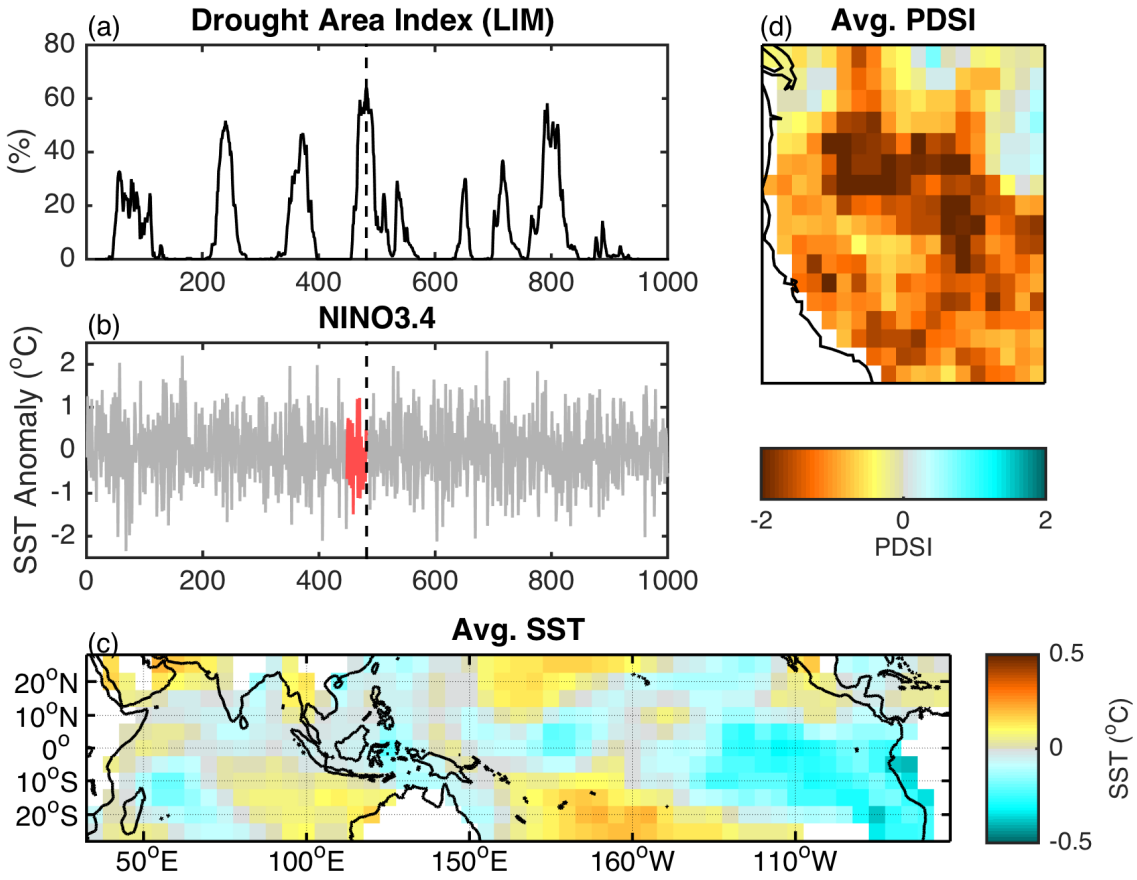


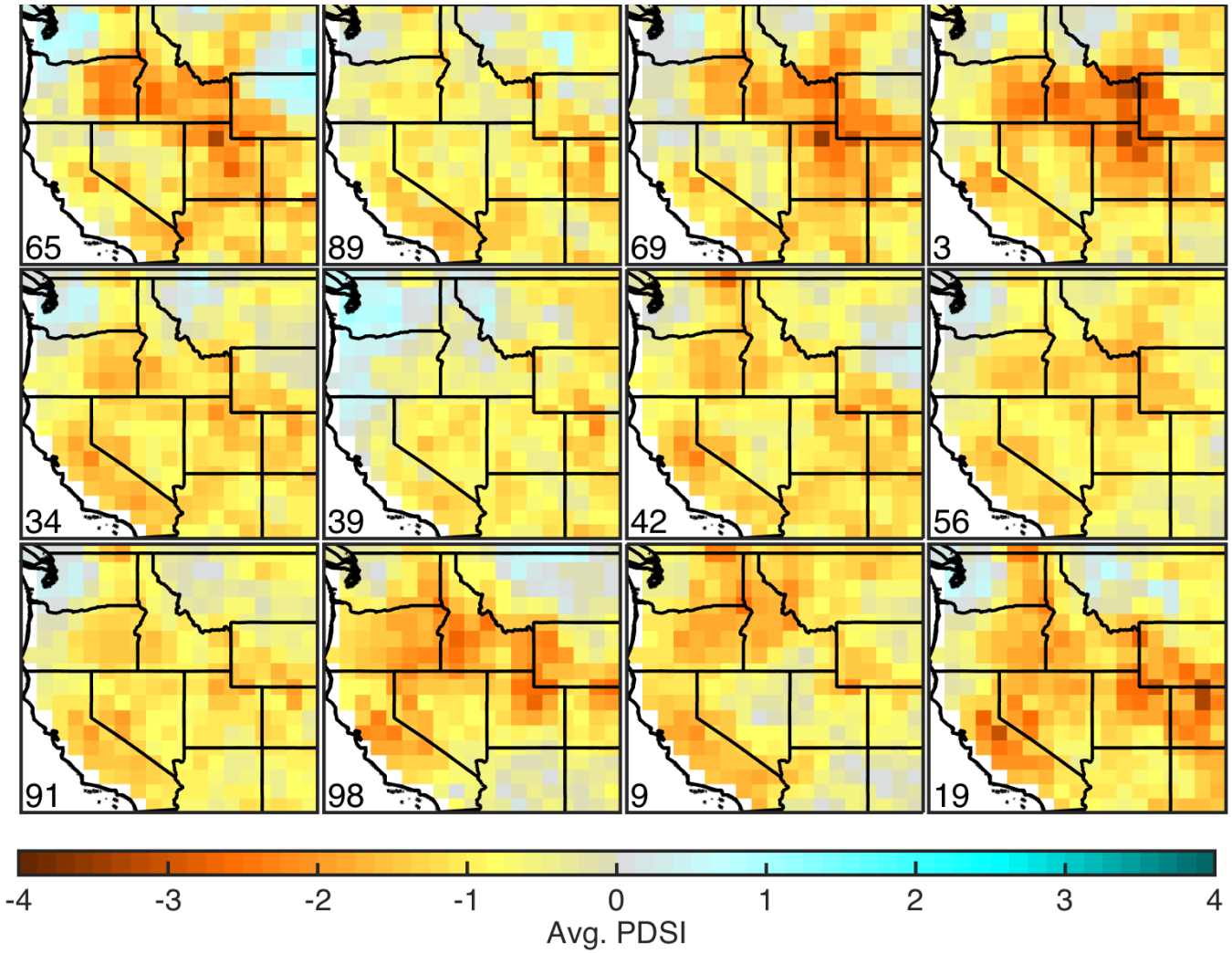
“Worst” megadrought from NADA

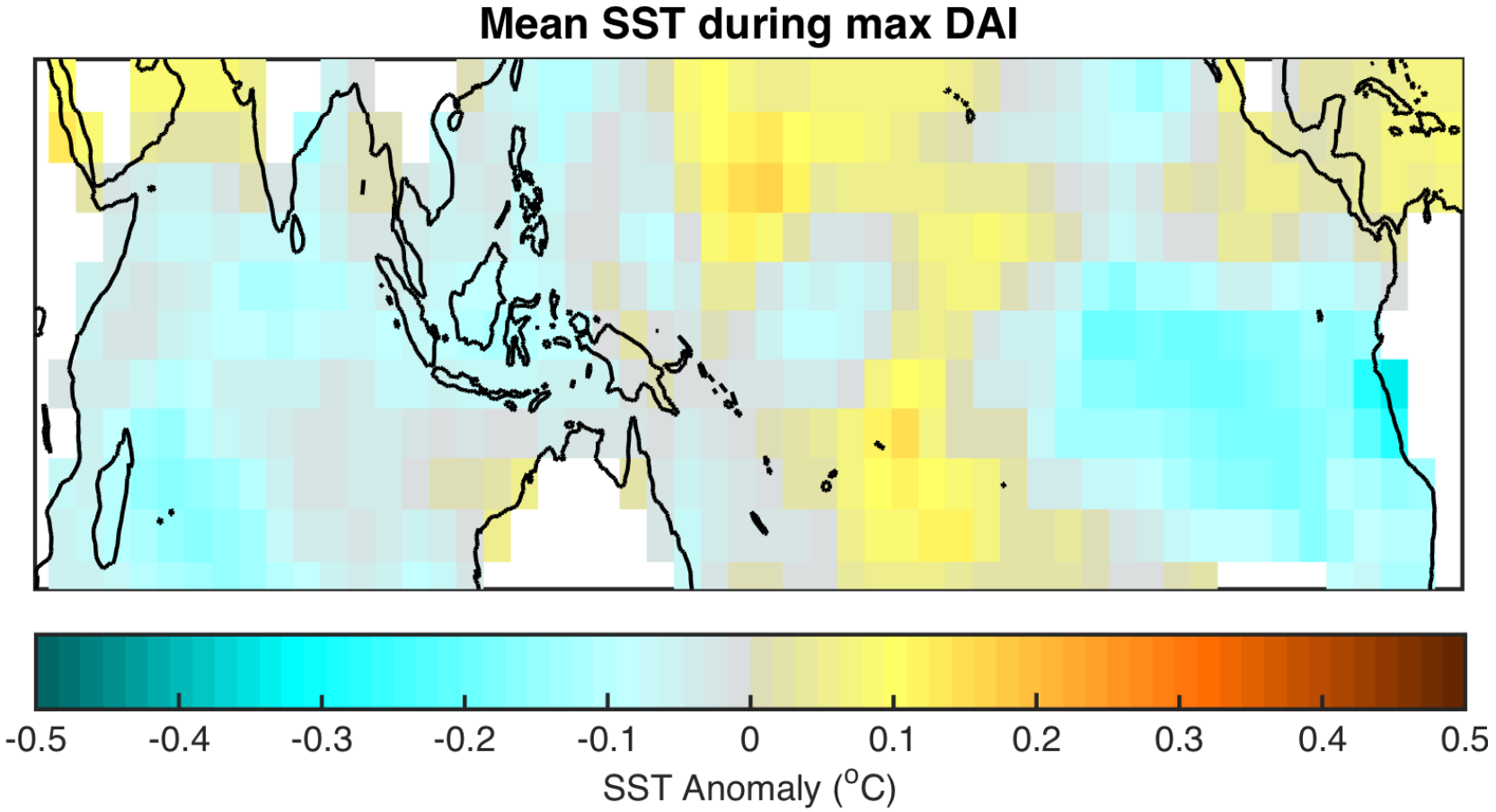


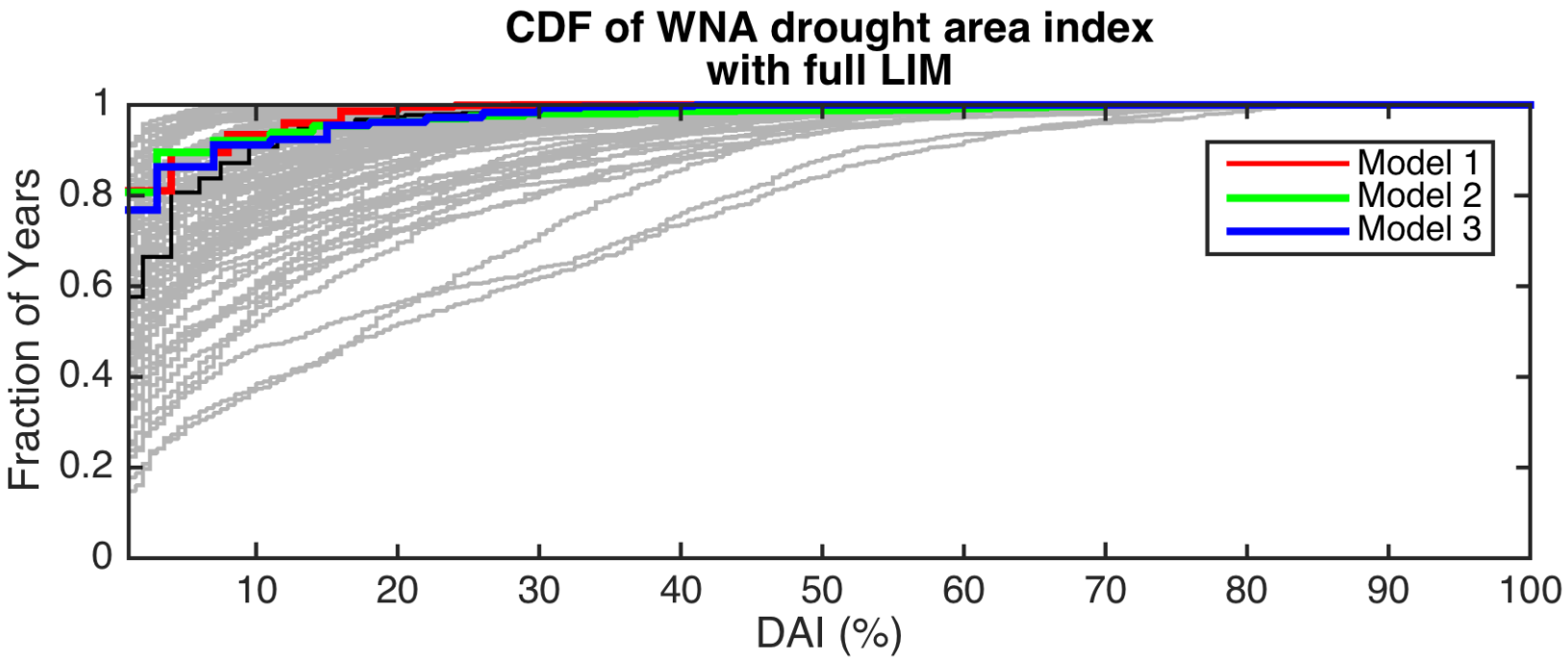

80
60
40
20
0
DAI (%)
250
750
Time
80
60
40
20
0
DAI (%)
250
750
Time
80
60
40
20
0
DAI (%)
250
750
Time
80
60
40
20
0
DAI (%)
250
750
Time

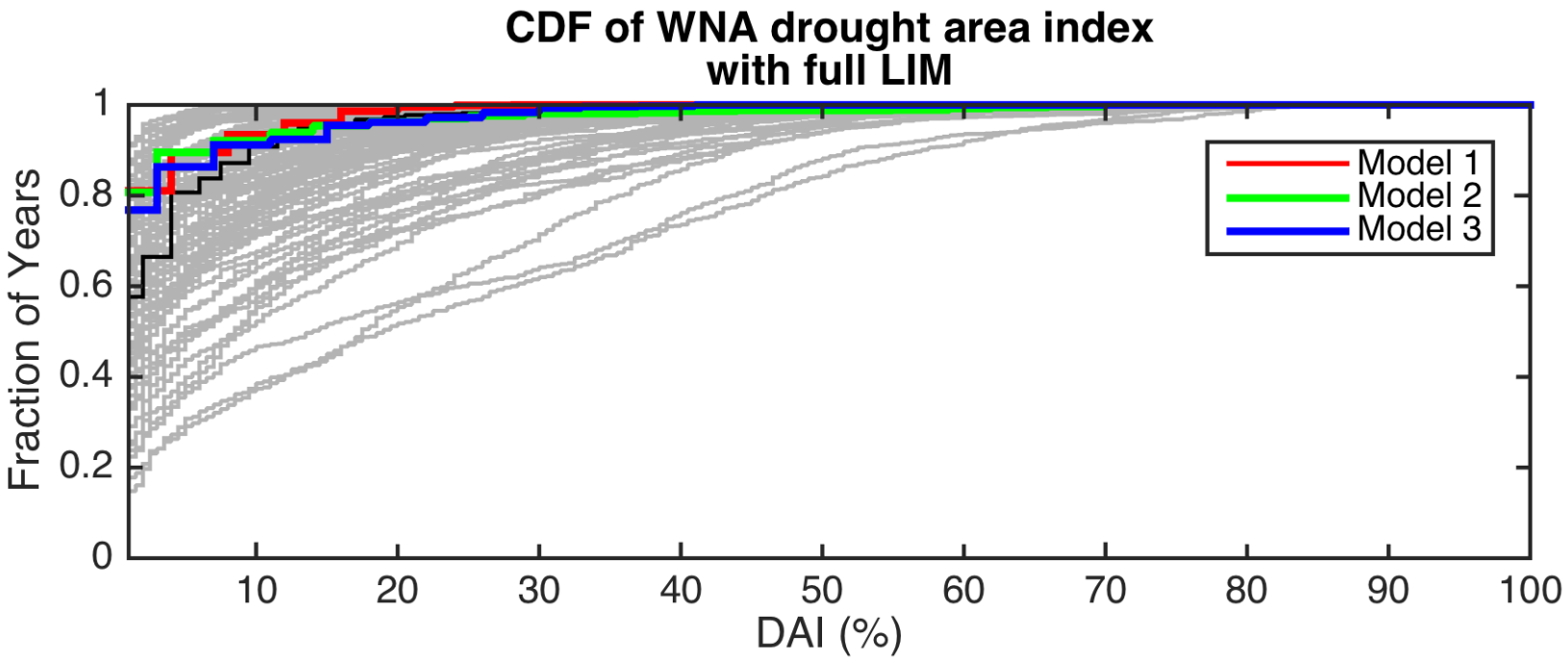

80
60
40
20
0
DAI (%)
250
750
Time
NADA


(a)
Drought Area Index (LIM)
(%)
80
60
40
20
0
200
400
600
800
1000
(b)
NINO3.4
SST Anomaly (°C)
2
1
0
-1
-2
0
200
400
600
800
1000
(d)
Avg. PDSI
-2
0
2
PDSI
(c)
Avg. SST
20°N
10°N
0°
10°S
20°S
50°E
100°E
150°E
160°W
110°W
0.5
0
-0.5
SST (°C)


65
89
69
3
34
39
42
56
91
98
9
19
-4
-3
-2
-1
0
1
2
3
4
Avg. PDSI


Mean SST during max DAI
-0.5
-0.4
-0.3
-0.2
-0.1
0
0.1
0.2
0.3
0.4
0.5
SST Anomaly (°C)


CDF of WNA drought area index
with full LIM
Fraction of Years
DAI (%)
Model 1
Model 2
Model 3
0
0.2
0.4
0.6
0.8
1
10
20
30
40
50
60
70
80
90
100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Model 1
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10
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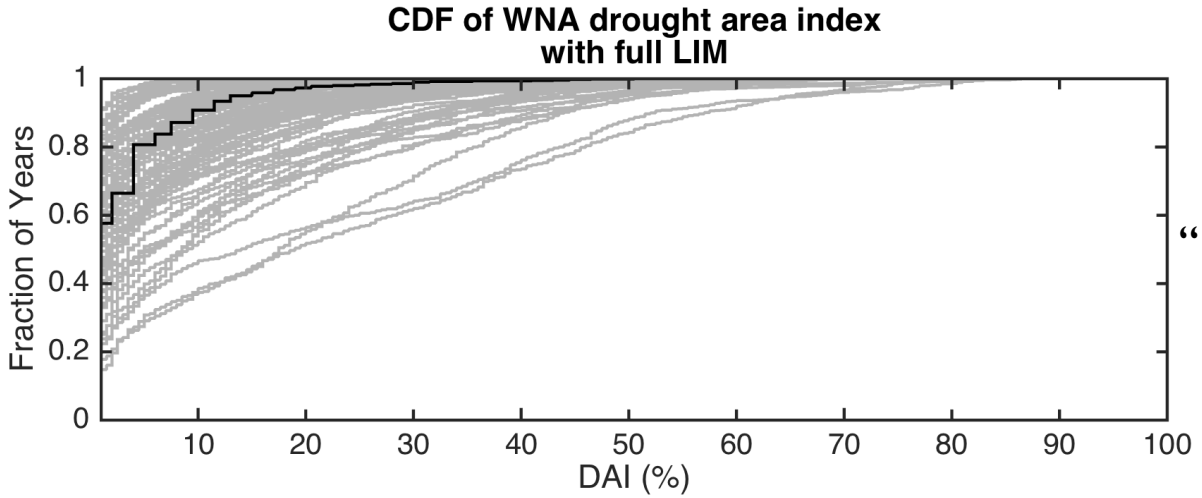
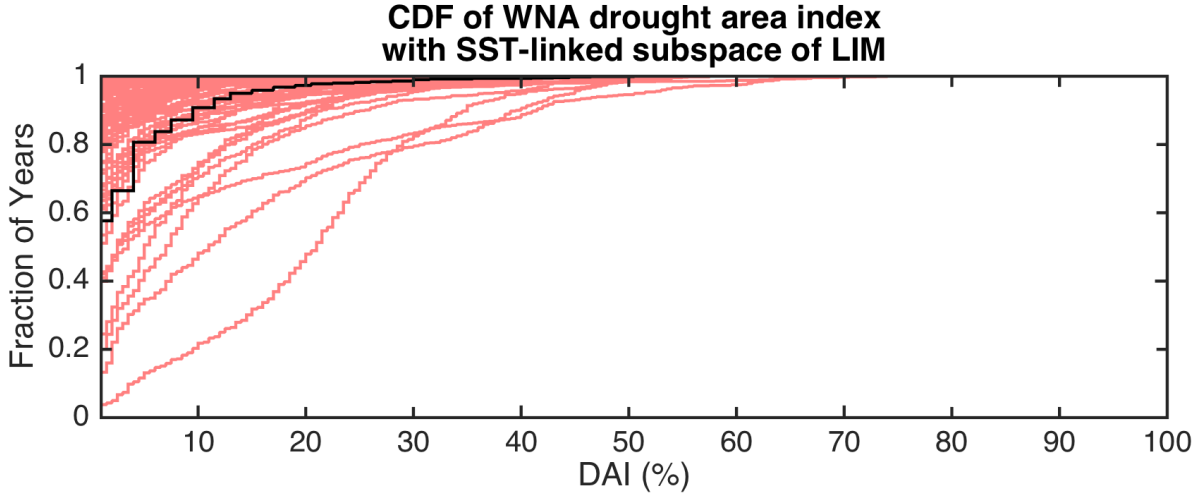
70
80
90
100



Can't rule out
"ENSO + Noise + Autocorrelation"
(e.g., linearly damped,
stochastically forced)



Can rule out
"ENSO – only"

The road ahead…

Acknowledgements

Clara Deser, Ben Sanderson, Bette Otto-Bliesner, John Fasullo,
Matt Newman, NSF EaSM2 (UA-NCAR)
Thanks!

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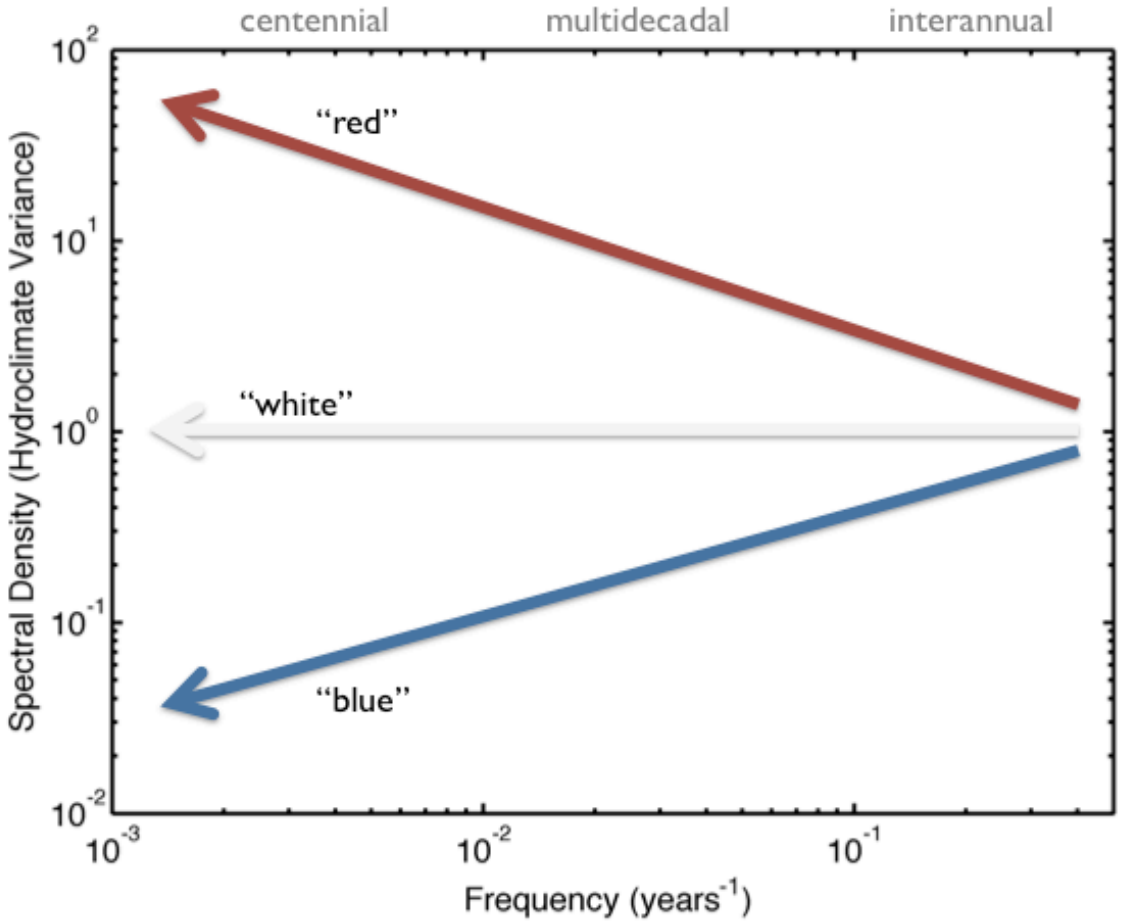
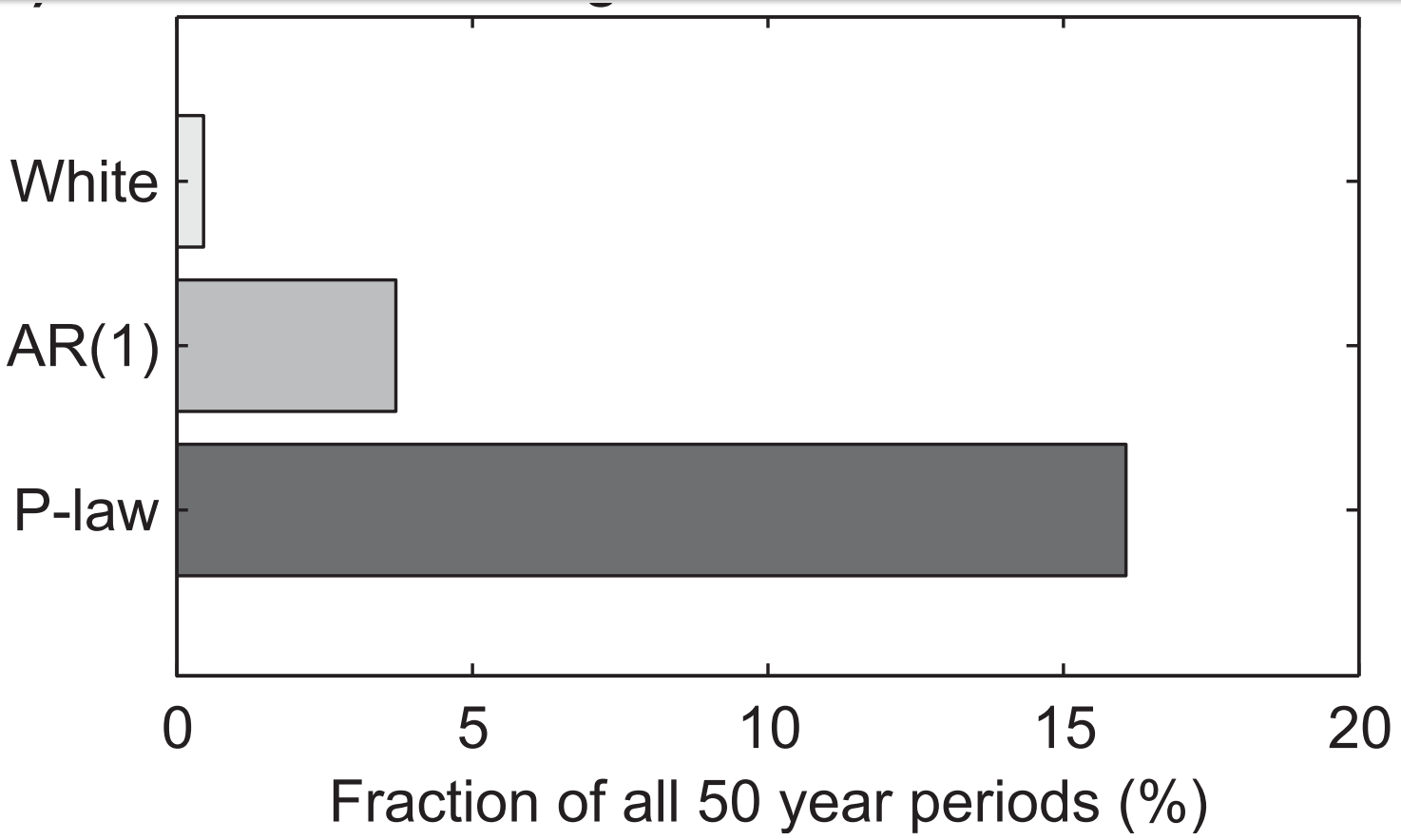
→ The distribution of variance across the power spectrum helps inform megadrought risk

Megadrought risk in different noise models



Megadrought risk in different noise models



From Ault et al., 2014 (JCLIM)