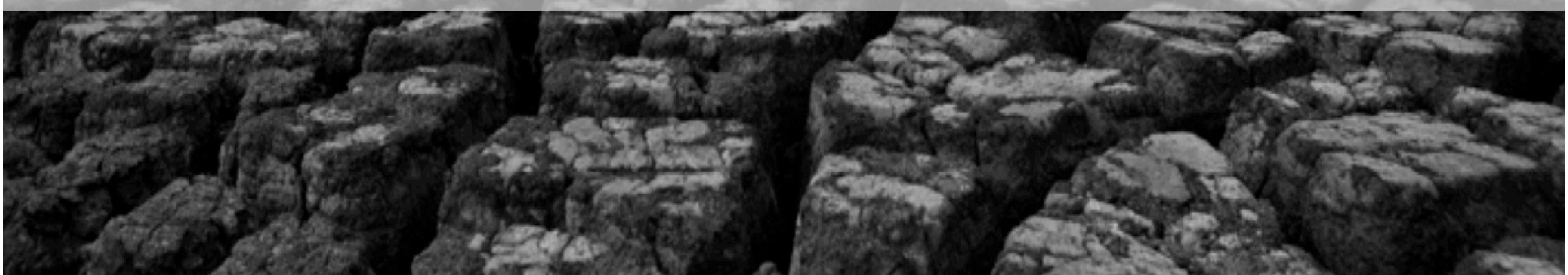
Paleoclimate Model-Data Comparisons of Hydroclimate over North America



Sloan Coats

PAGES2k-PMIP3 Hydroclimate

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CIRES

Paleo model-data comparisons

Combine paleoclimate and instrumental data with forced and control simulations

Paleo model-data comparisons

Combine paleoclimate and instrumental data with forced and control simulations

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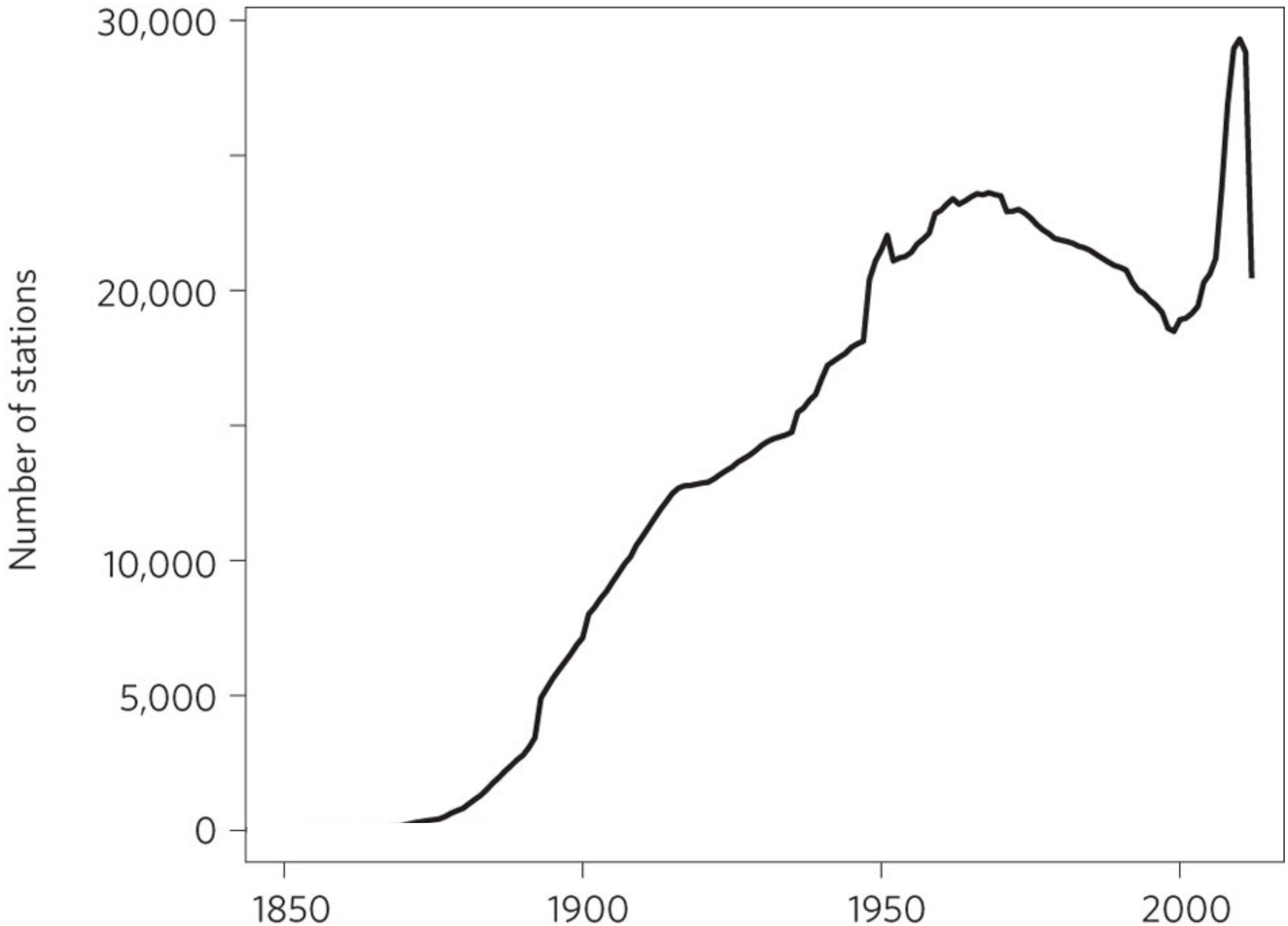
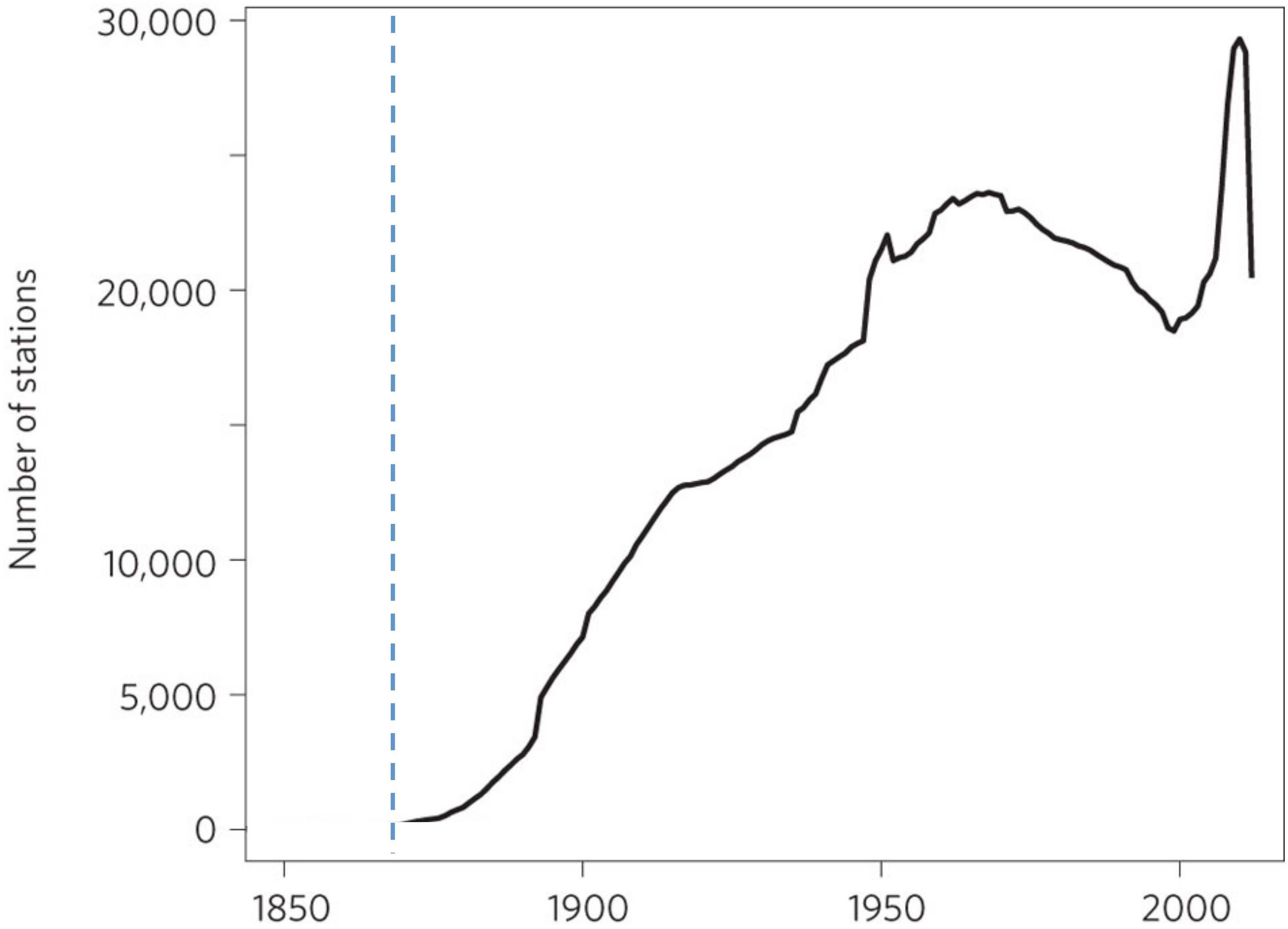
Apply to hydroclimate over the Common Era (C.E.)

Why are paleo model-data comparisons of the CE important?



Why are paleo model-data comparisons of the CE important?



Paleoclimate record of the Common Era is best chance of extending the instrumental record with similar temporal and spatial resolution (with more uncertainty)

Forced-transient coupled model simulations are available for the Common Era (with forcing and model uncertainties)

Why should we care?
Projecting Future Hydroclimate!

- How will hydroclimate respond to increasing greenhouse gas concentrations over the next decade to century?

- How will these forced changes combine with internal climate variability to determine the actual impacts of hydroclimate change?

- Are models able to capture the full range of internal and forced components of past hydroclimate?

An example of each:

1) Megadroughts over the AW

(Decadal-to-centennial timescale variability)

2) North Amer. Pan-continental droughts

(Infrequent climate features)

1) Megadroughts over the AW

(Decadal-to-centennial timescale variability)

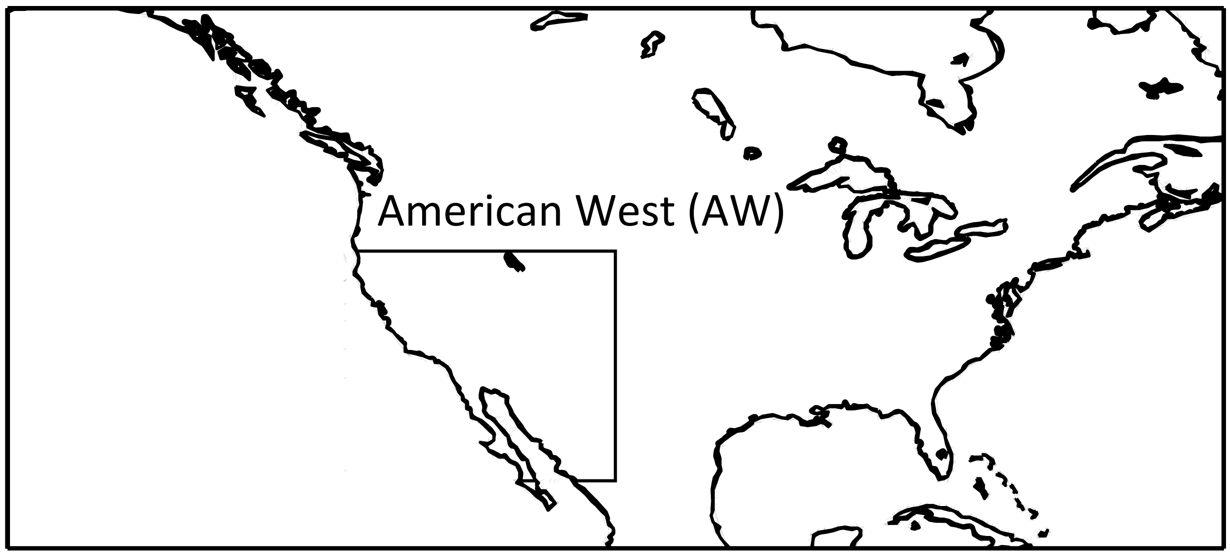
North American Drought Atlas (NADA)

-Tree-ring based reconstruction of hydroclimate variability

-0.5° lat.-lon. grid

-Reconstructs Palmer Drought Severity Index (PDSI): Standard metric of drought, used over many regions and timescales

North American Drought Atlas (NADA)



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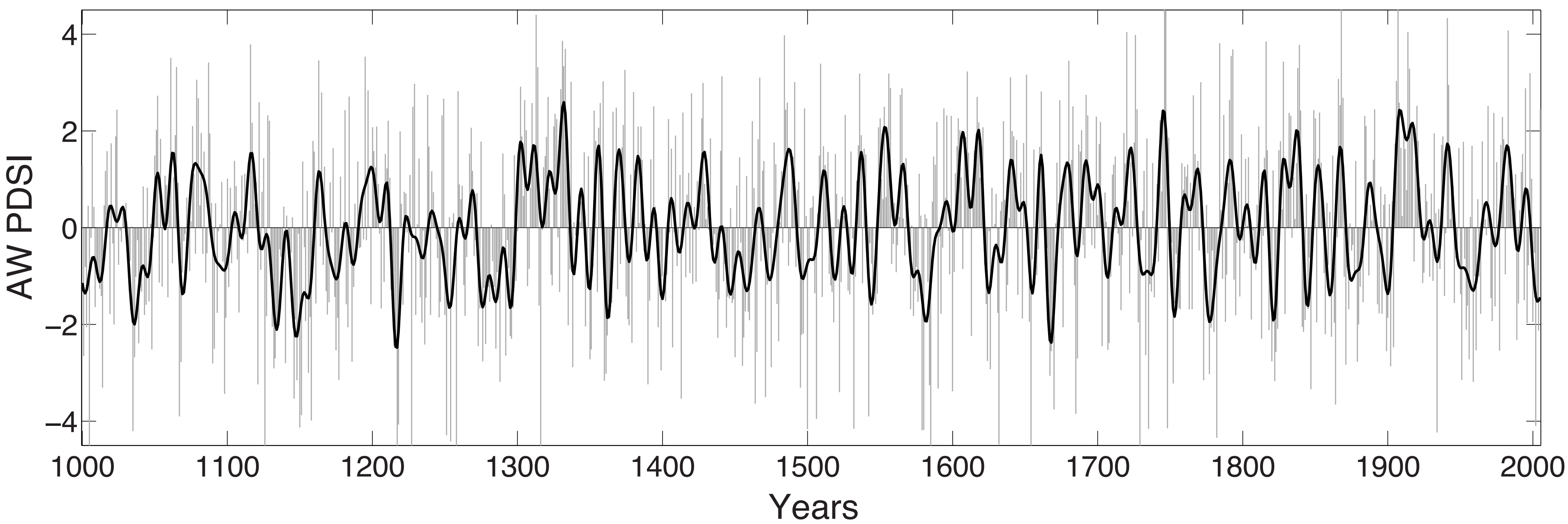

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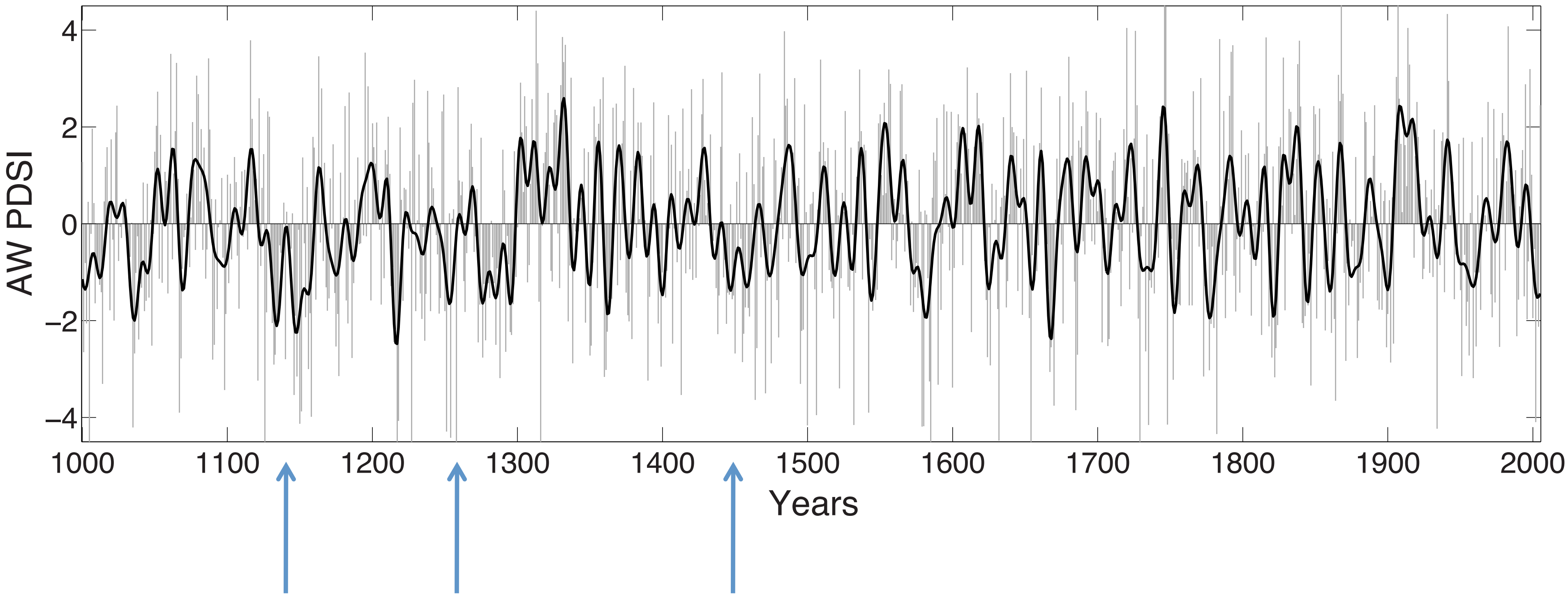

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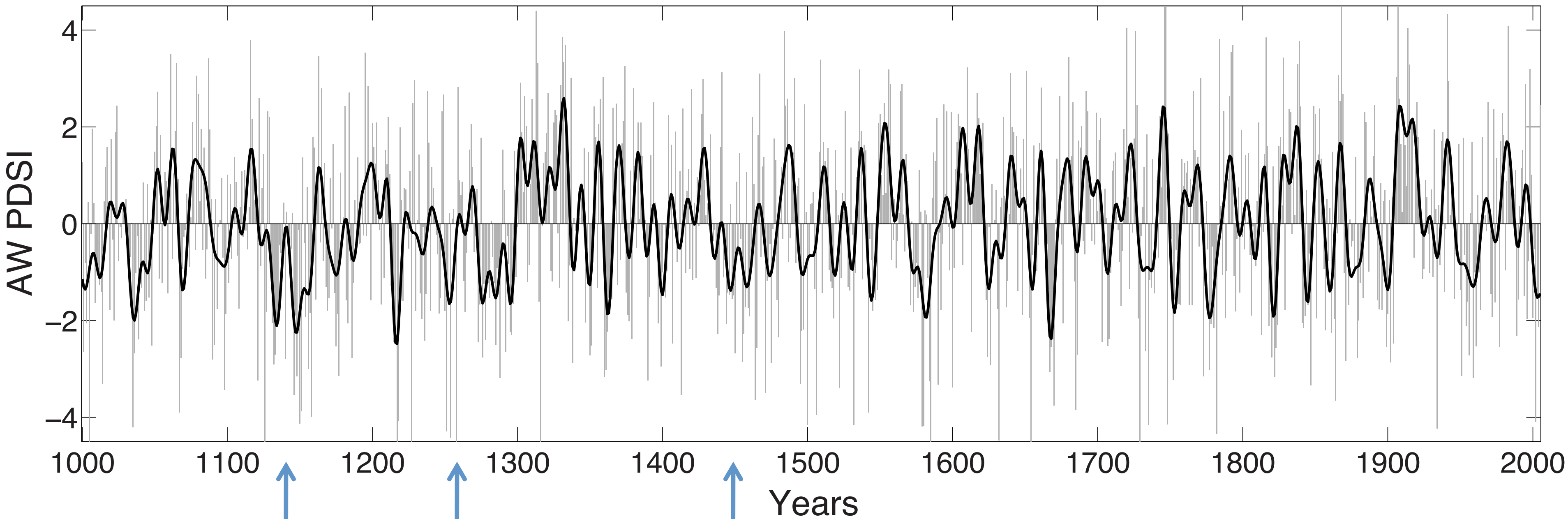
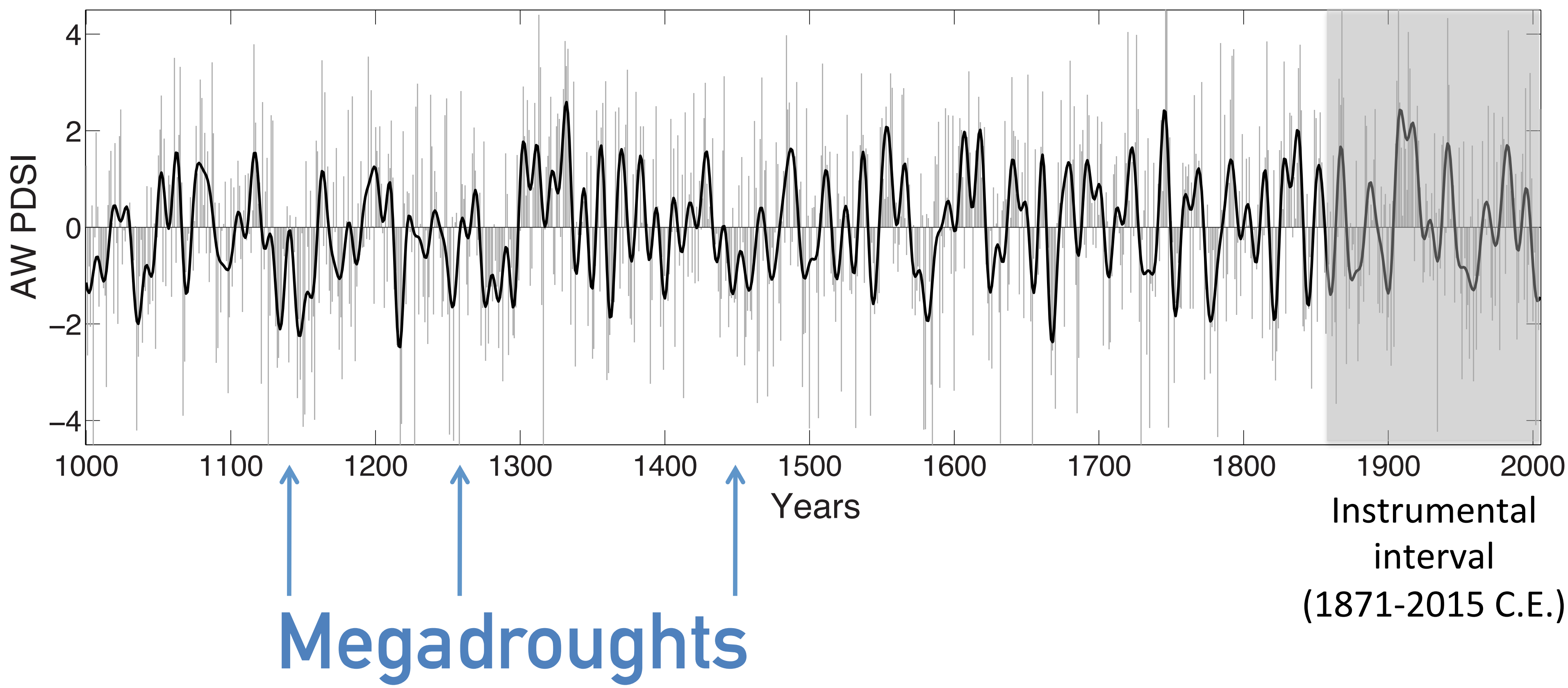


Megadroughts

North American Drought Atlas (NADA)



Megadroughts are hydroclimate change on the timescale over which we hope to project future climate

Why should we care?
Projecting Future Hydroclimate!

- How will hydroclimate respond to increasing greenhouse gas concentrations over the next decade to century?
- How will these forced changes combine with internal climate variability to determine the actual impacts of hydroclimate change?
- Are models able to capture the full range of internal and forced components of past hydroclimate?

Why should we care?

Projecting Future Hydroclimate!

- Are models able to capture the full range of internal and forced components of past hydroclimate?

Why should we care?

Projecting Future Hydroclimate!

- Do models simulate megadroughts?
- If so, what are the underlying dynamics?

- Are models able to capture the full range of internal and forced components of past hydroclimate?

Underlying dynamics?

Underlying dynamics?

Exogenous

-Trace Gasses

-Solar

-Volcanic

Underlying dynamics?

Exogenous

-Trace Gasses
-Solar
-Volcanic

SST Boundary

-ENSO
-PDO
-AMO

Underlying dynamics?

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Underlying dynamics?

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Tropical Pacific

-AMO

Rank droughts by persistence and severity

(Coats et al., *J. Clim.*, 2013; 2015; Stevenson, *J. Clim.*, 2015)

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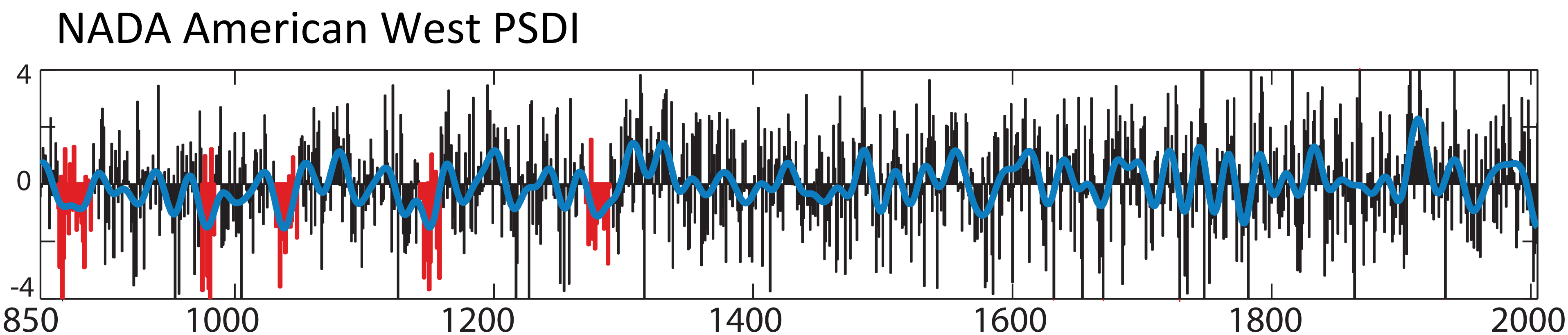
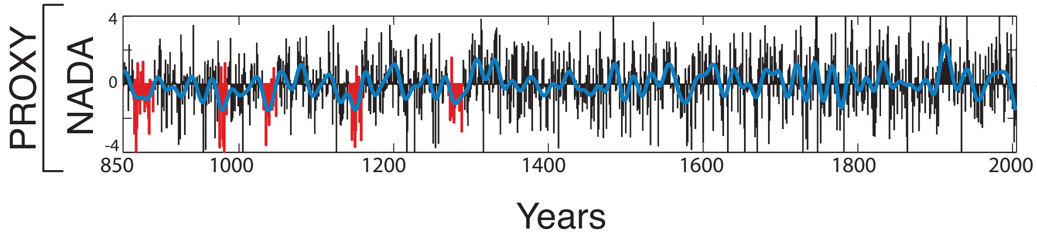
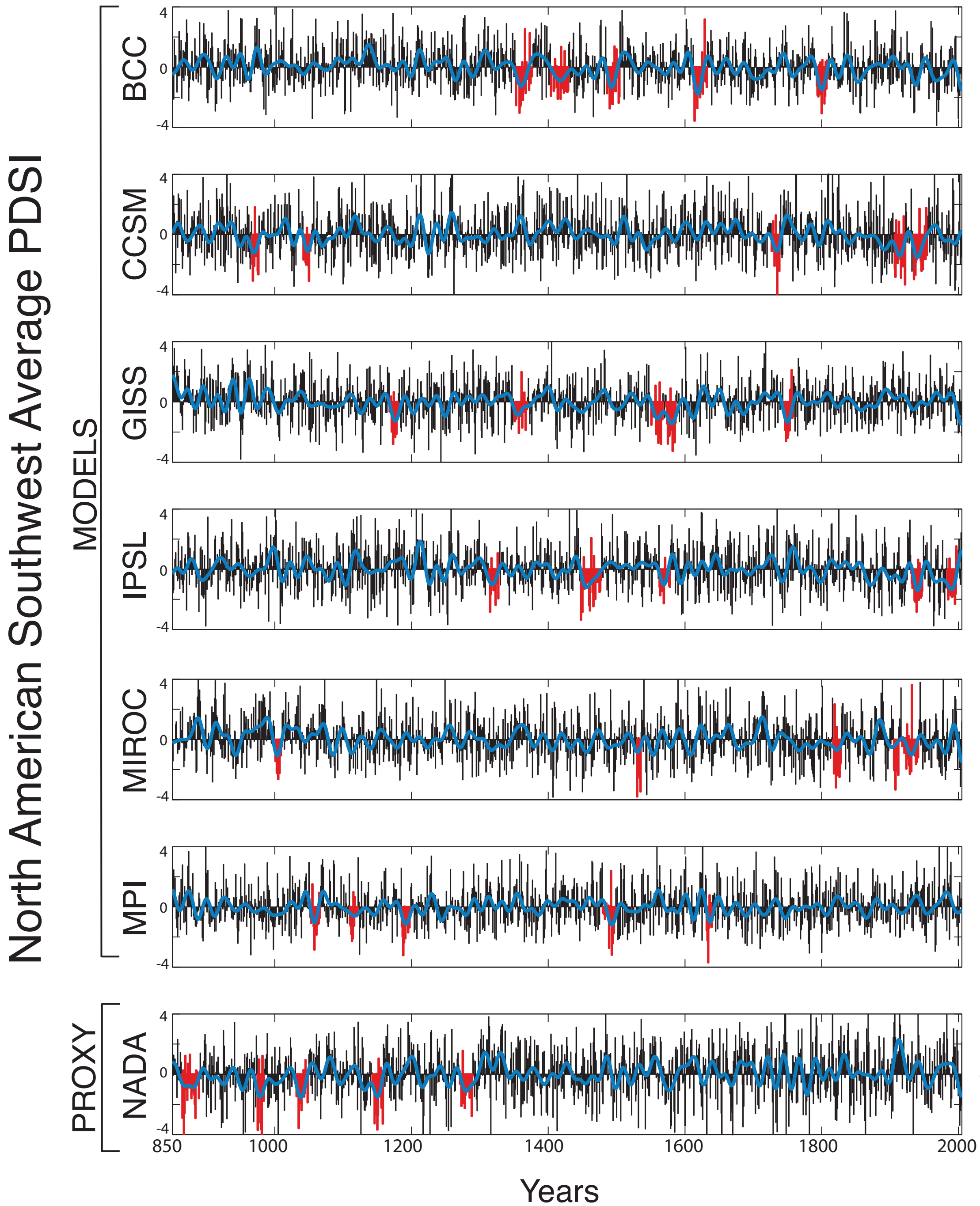


Paleoclimate Model-Data Comparisons



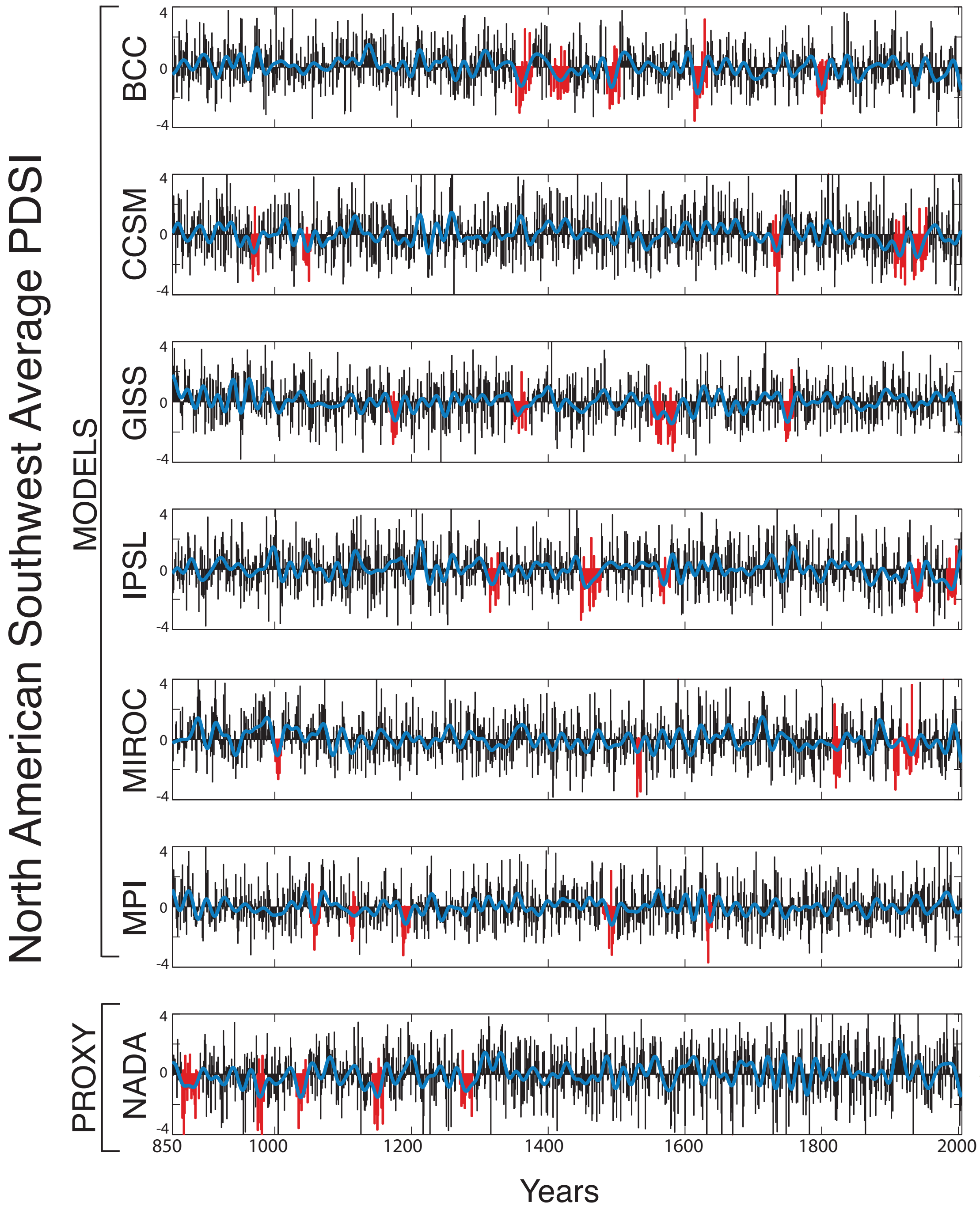
Paleoclimate estimated drought variability

Paleoclimate Model-Data Comparisons



Paleoclimate estimated drought variability

Paleoclimate Model-Data Comparisons



Models simulate drought that is characteristic of proxy estimated megadroughts

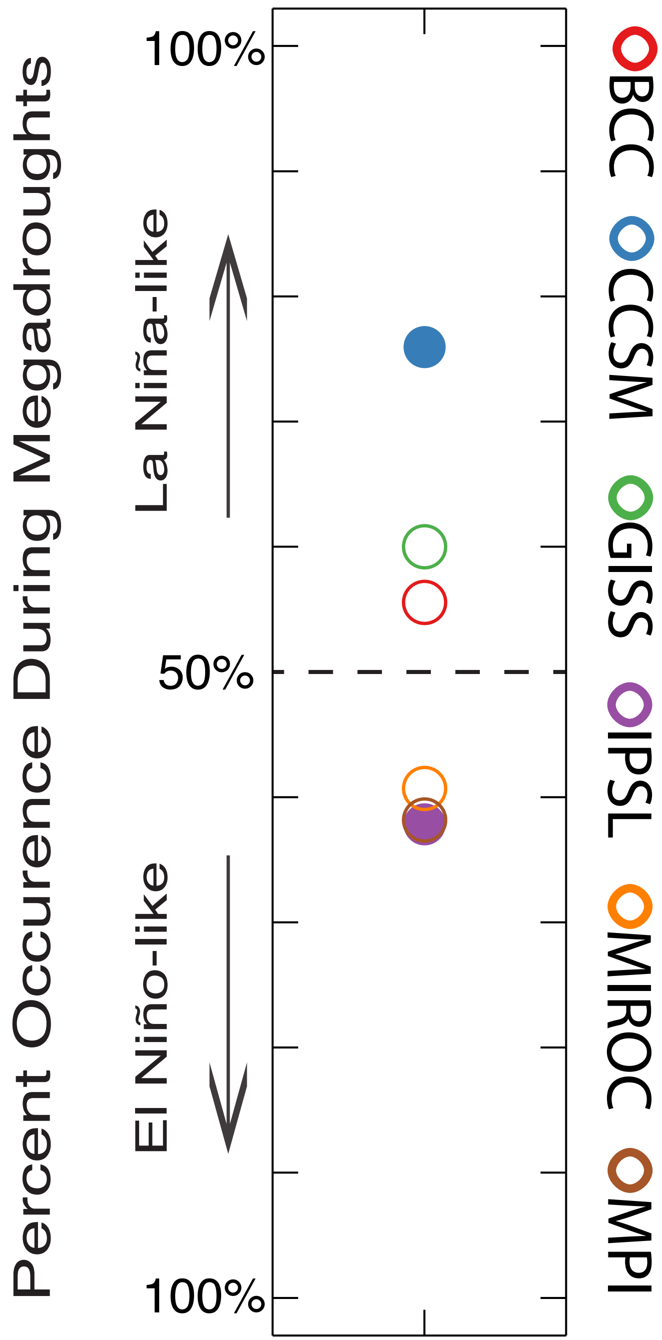
Paleoclimate estimated drought variability

What about models?

- Do models simulate megadroughts?

✓

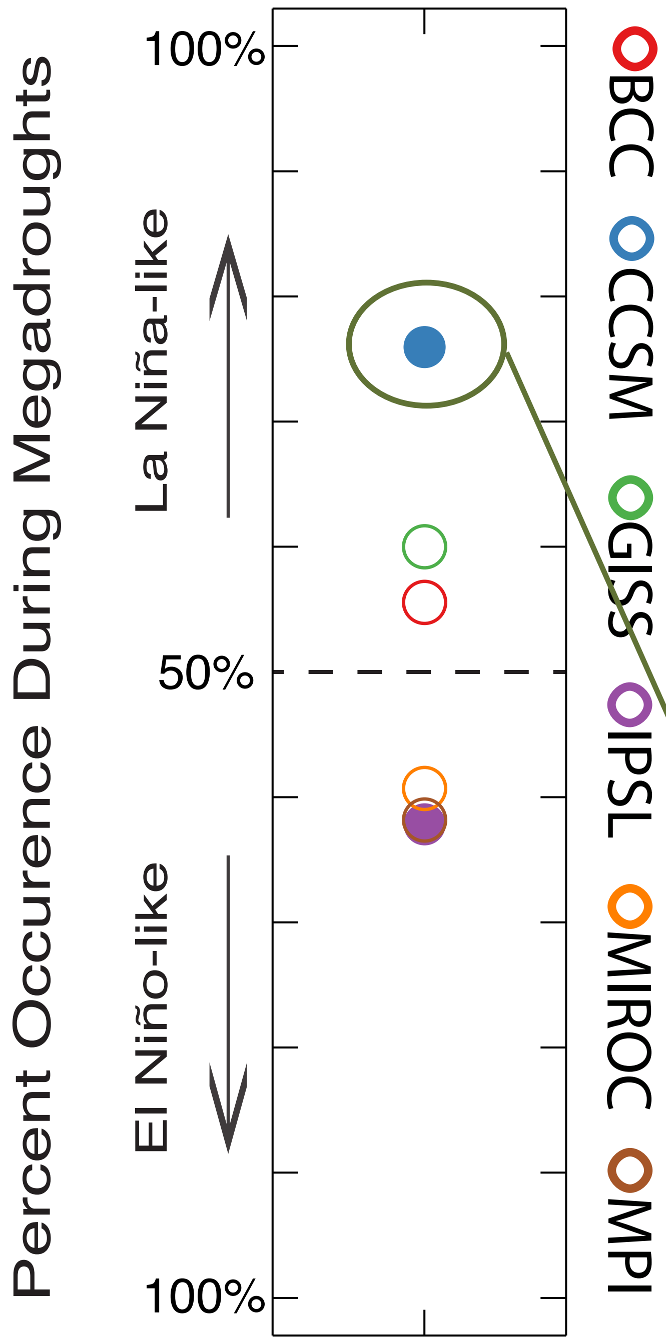
- What are the atmosphere-ocean dynamics? Not exogenously forced



Multi-Model Dynamical Diagnostics

○ Not Significant
● Significant at 95% level
(Schrieber and Shmitz, 2000)

Multi-Model Dynamical Diagnostics



○ Not Significant
● Significant at 95% level
(Schrieber and Shmitz, 2000)

CCSM is exceptional in simulating megadroughts consistently forced by the tropical Pacific

What about models?

- Do models simulate megadroughts?

- Is there a role for the tropical Pacific?

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CCSM does

What about models?

- **Do models simulate megadroughts?**

- **Is there a role for the tropical Pacific?**

CCSM does (Bonus: Why?)

Hypothesis (Coats et al., *J. Clim.*, 2013): large magnitude multidecadal ocean variability and strong and stationary teleconnections will produce megadroughts driven by tropical Pacific

Conclusions: Megadroughts

- Models simulate megadroughts.
- No consistent role for the Tropical Pacific or exogenous forcing.
- Characteristics of models important in determining atmosphere-ocean dynamics underlying megadroughts.

2) North Amer. Pan-continental droughts

(Infrequent climate features)

PC Drought

=

Pan-Continental Drought

North American Regions

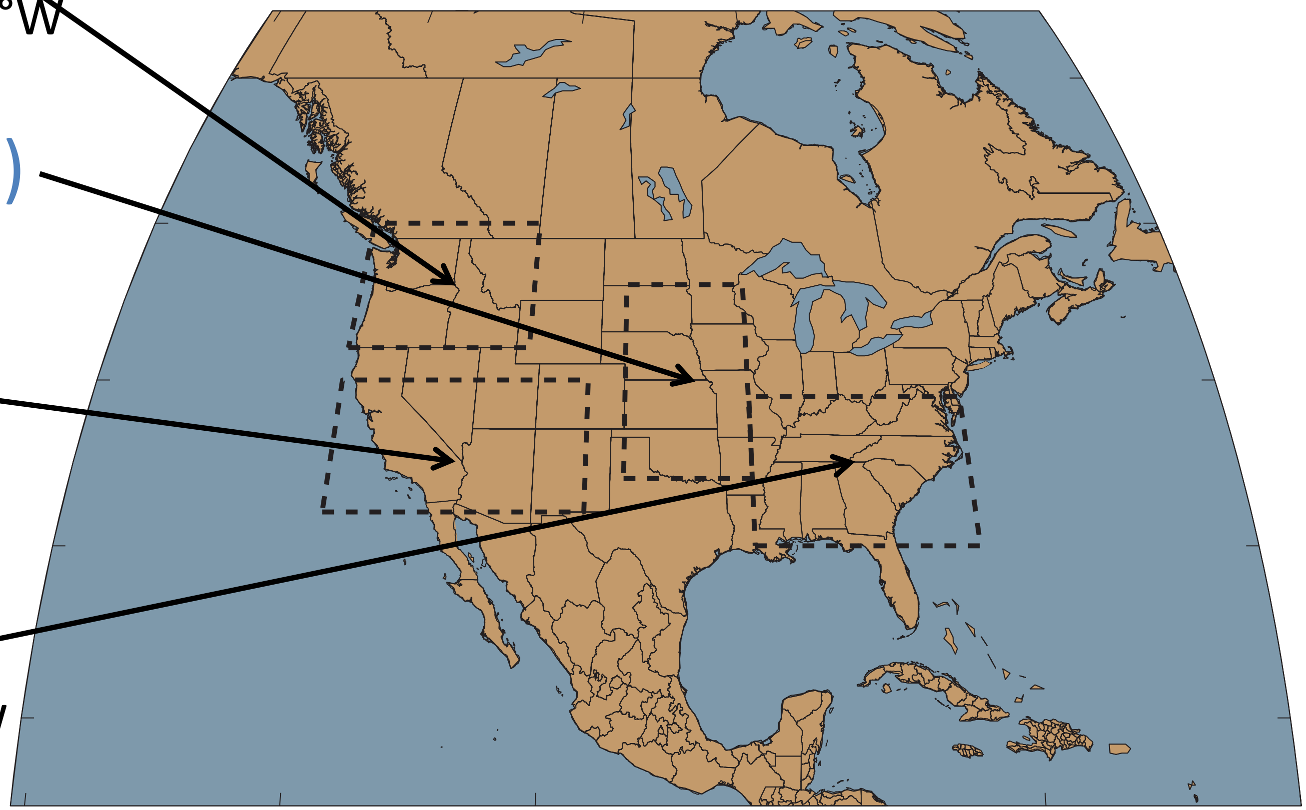
Northwest (NW)
42°N–50°N, 125°W–110°W

Central Plains (CP)
34°–46°N, 102°–92°W

Southwest (SW)
32°–40°N, 125°–105°W

Southeast (SE)
30°N–39°N, 92°W–75°W

Cook et al. 2014



Pan Continental Drought occurs when three or all four regions have drought

Five "Flavors": SW+CP+SE; SW+CP+NW; SW+NW+SE; CP+NW+SE; SW+CP+NW+SE

What do we know?

- Cook et al. (2014) used NADA to extend drought record
    - PC Drought is consistent, but infrequent, feature of Common Era hydroclimate
        - Few degrees of freedom to define how dynamics produce PC drought

Flavor	**Events over PDO, AMO and ENSO record**
SW+CP+SE	7
SW+CP+NW	1
SW+NW+SE	1
CP+NW+SE	5
SW+CP+NW+SE	6

Cook et al. 2014

Use a paleo-model data comparisons framework to analyze PC drought

1) More degrees of freedom to analyze dynamics

2) Assess if models capture such variability and why

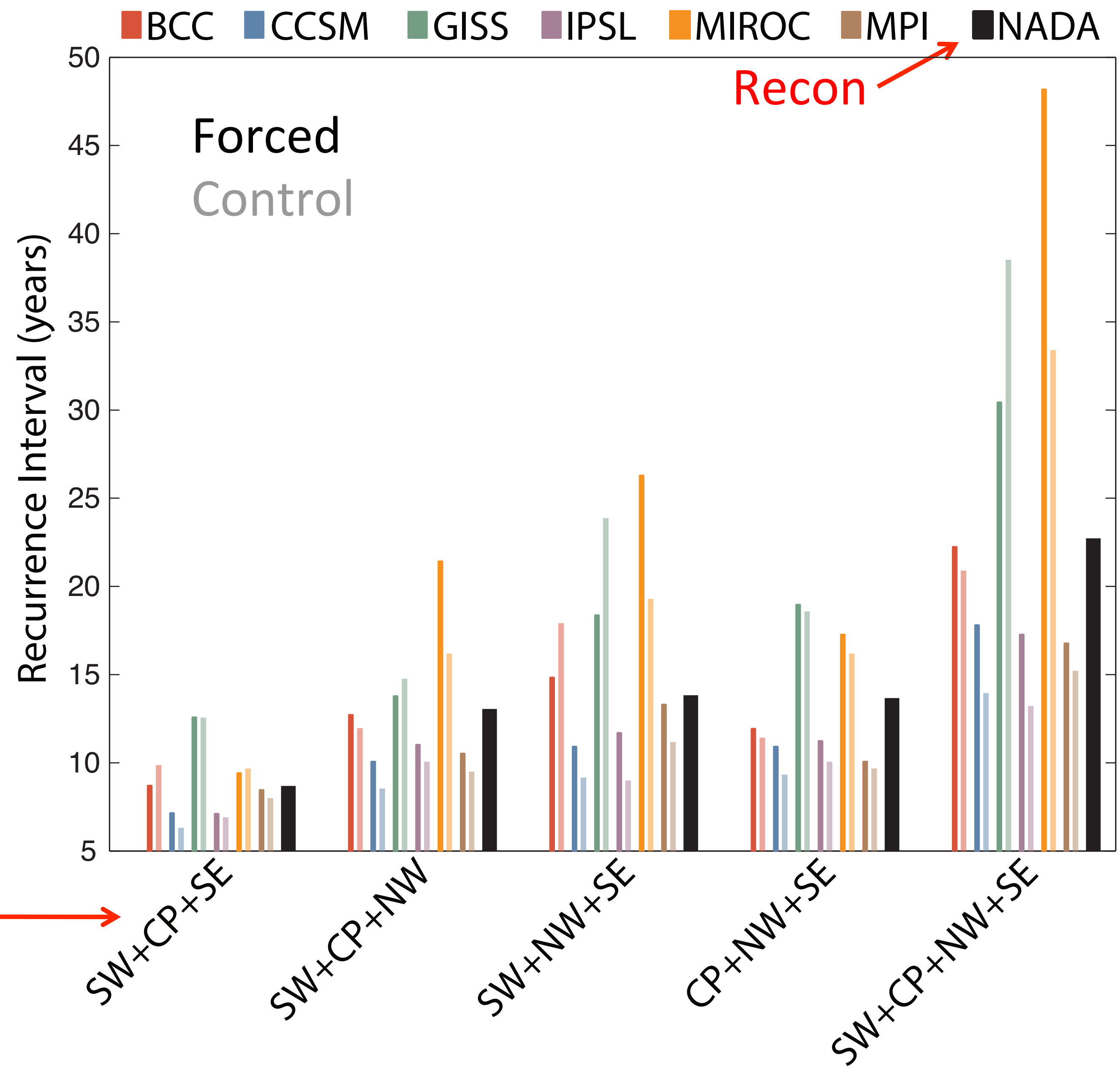
Data

- The NADA (Cook et al. 2007) will be used as the ground truth
    - Tree-ring based reconstruction of JJA PDSI for North America from 1000-2005 C.E.
    - PDSI (Palmer Drought Severity Index) is a model of soil moisture balance
- Six LM and pre-industrial control simulations from CMIP5
    - JJA PDSI calculated offline from precipitation and net surface radiation

Do models capture PC drought statistics?

Model range captures NADA

Two Categories: GISS and MIROC (too infrequent); and CCSM, MPI and IPSL (too frequent); BCC is pretty good



PC Drought Type

What are the atmosphere-ocean dynamics that drive PC drought?

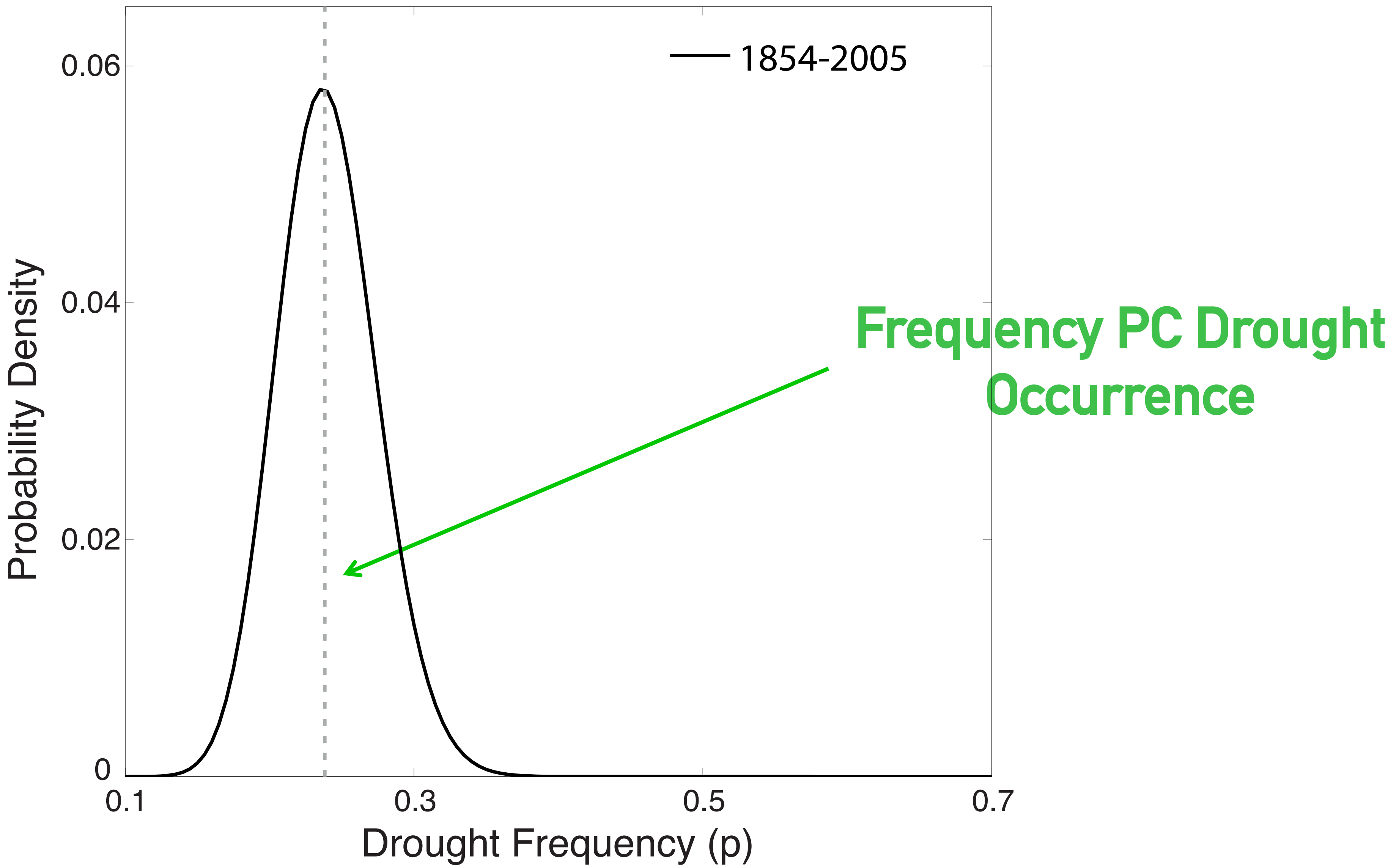
Dynamics of Recon over Instrumental Interval

For 1854-2005 C.E. PC drought predominantly driven by negative PDO and ENSO and positive AMO:

-No longer consider PC Drought as separate "flavors" for greater N

-Use a basic Bayesian framework to assess impact of different atmosphere-ocean states on frequency of PC Drought occurrence

Dynamics of Recon over Instrumental Interval



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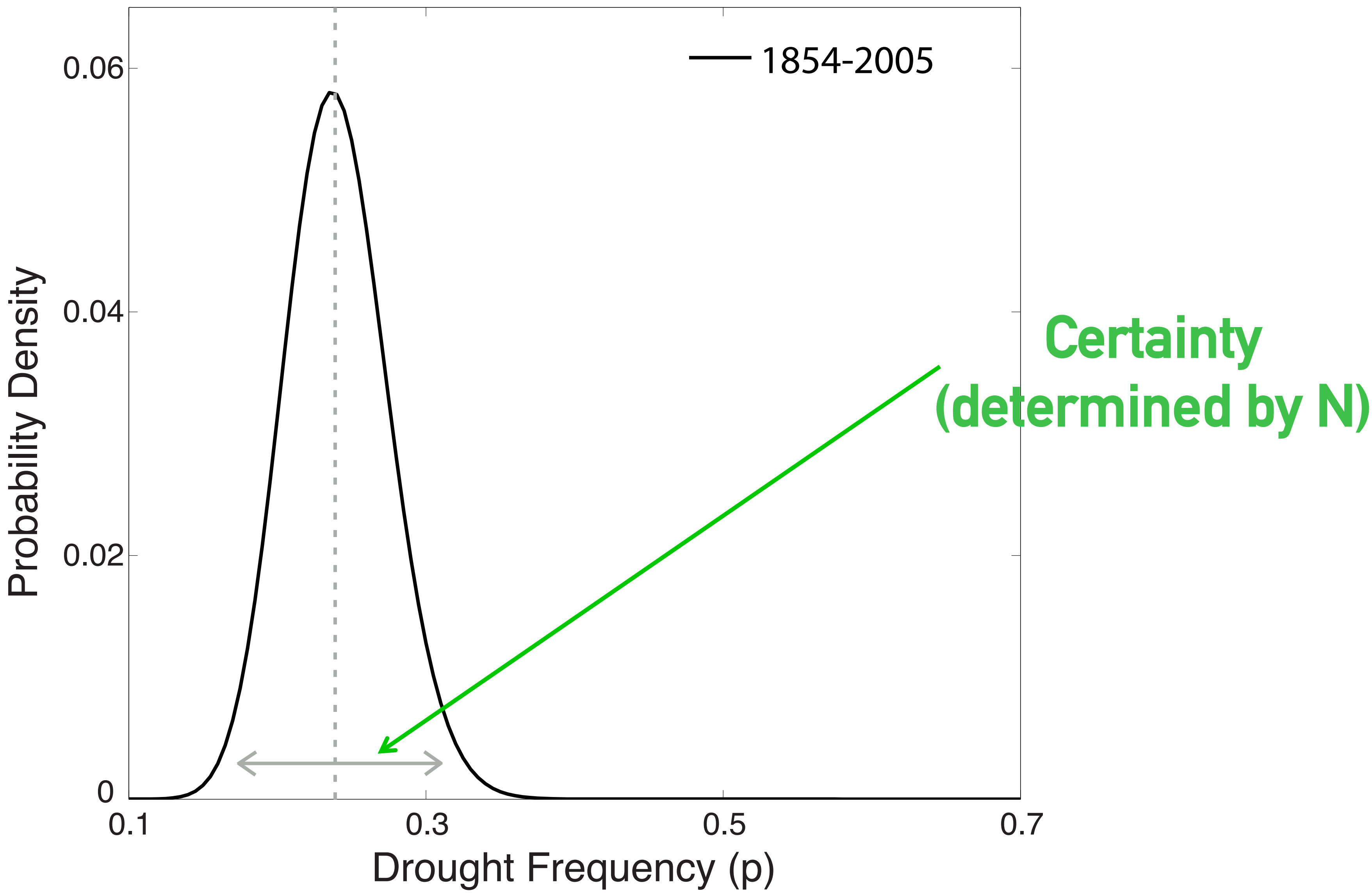

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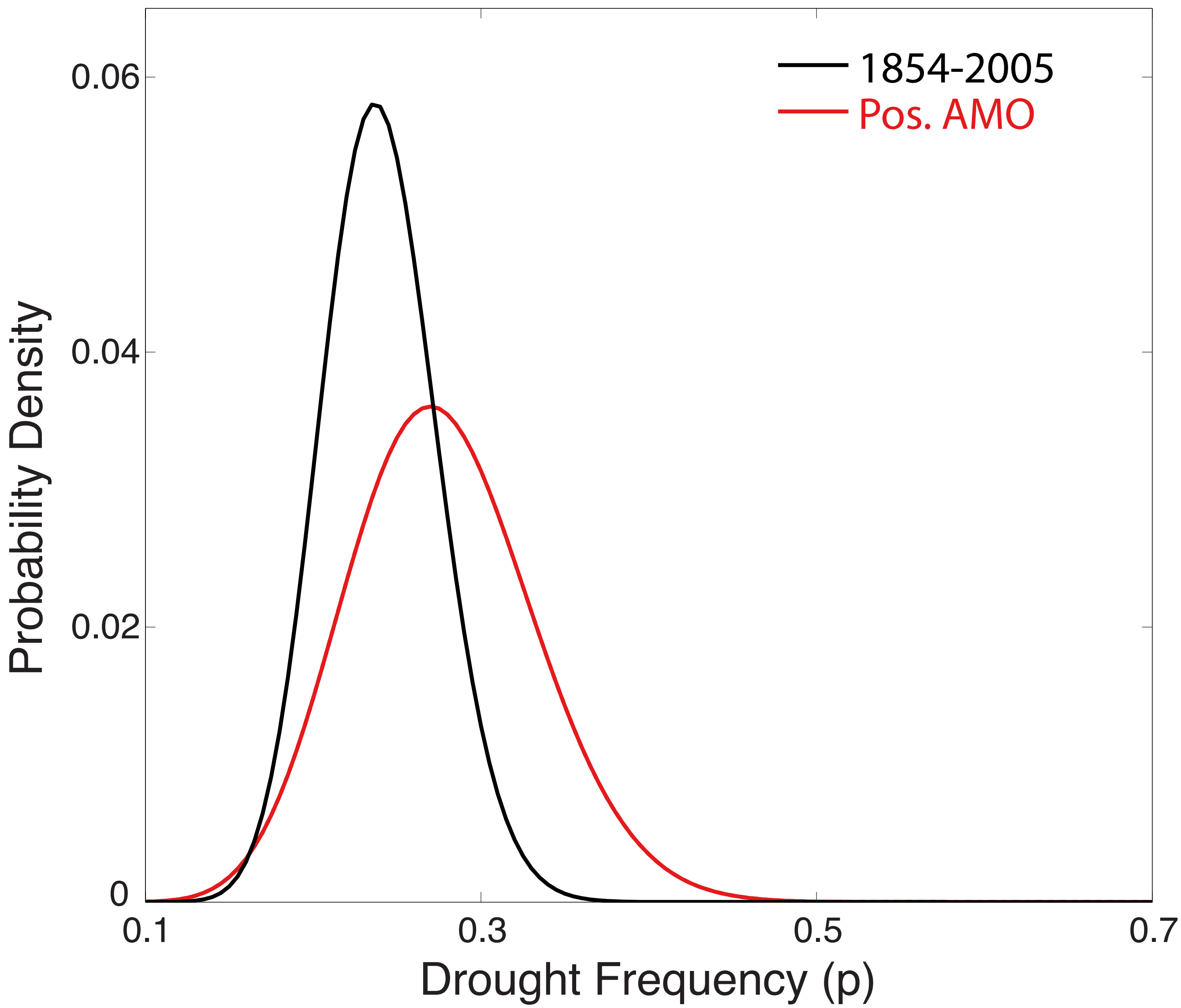
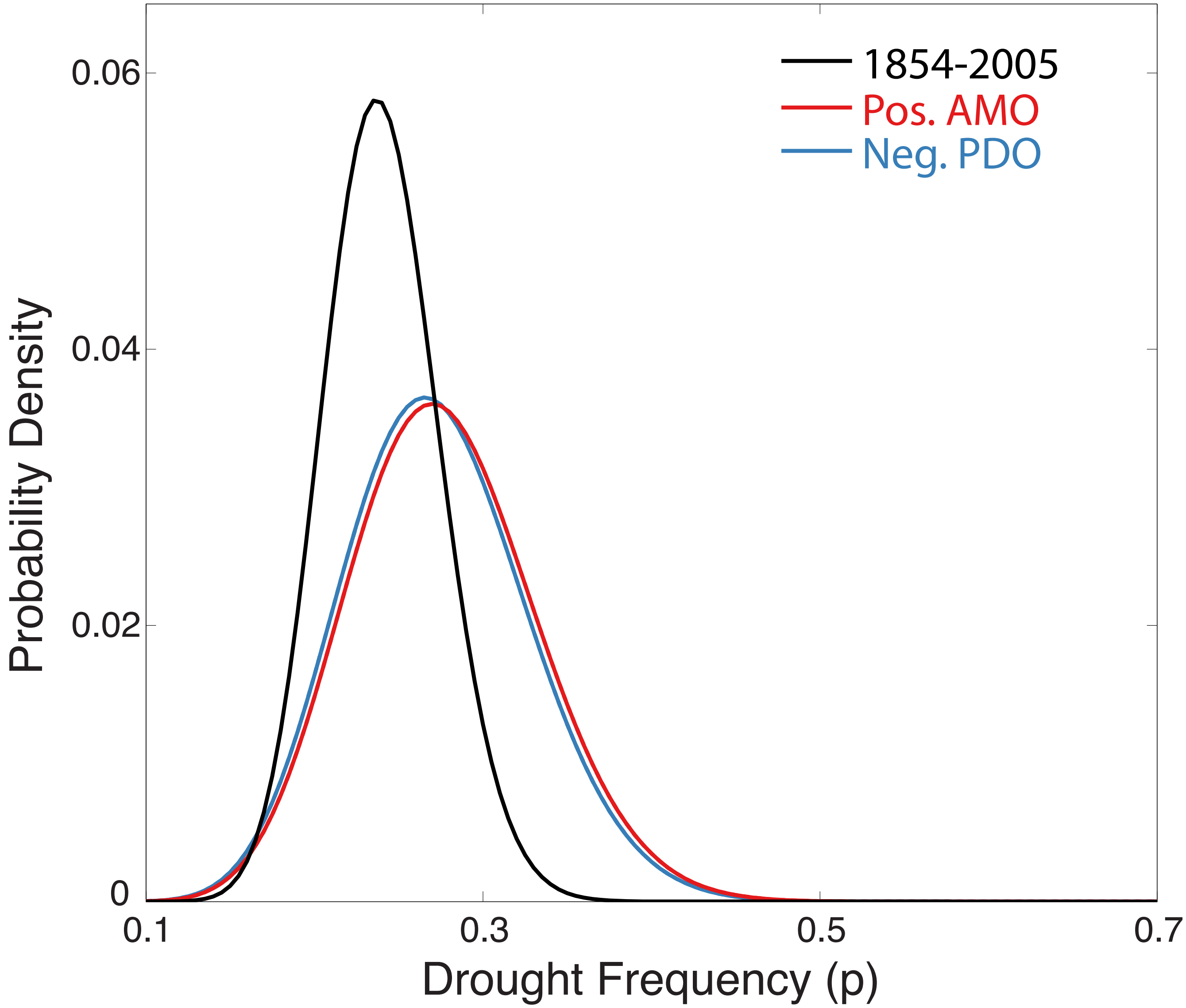


Frequency For Data Subset

Dynamics of Recon over Instrumental Interval



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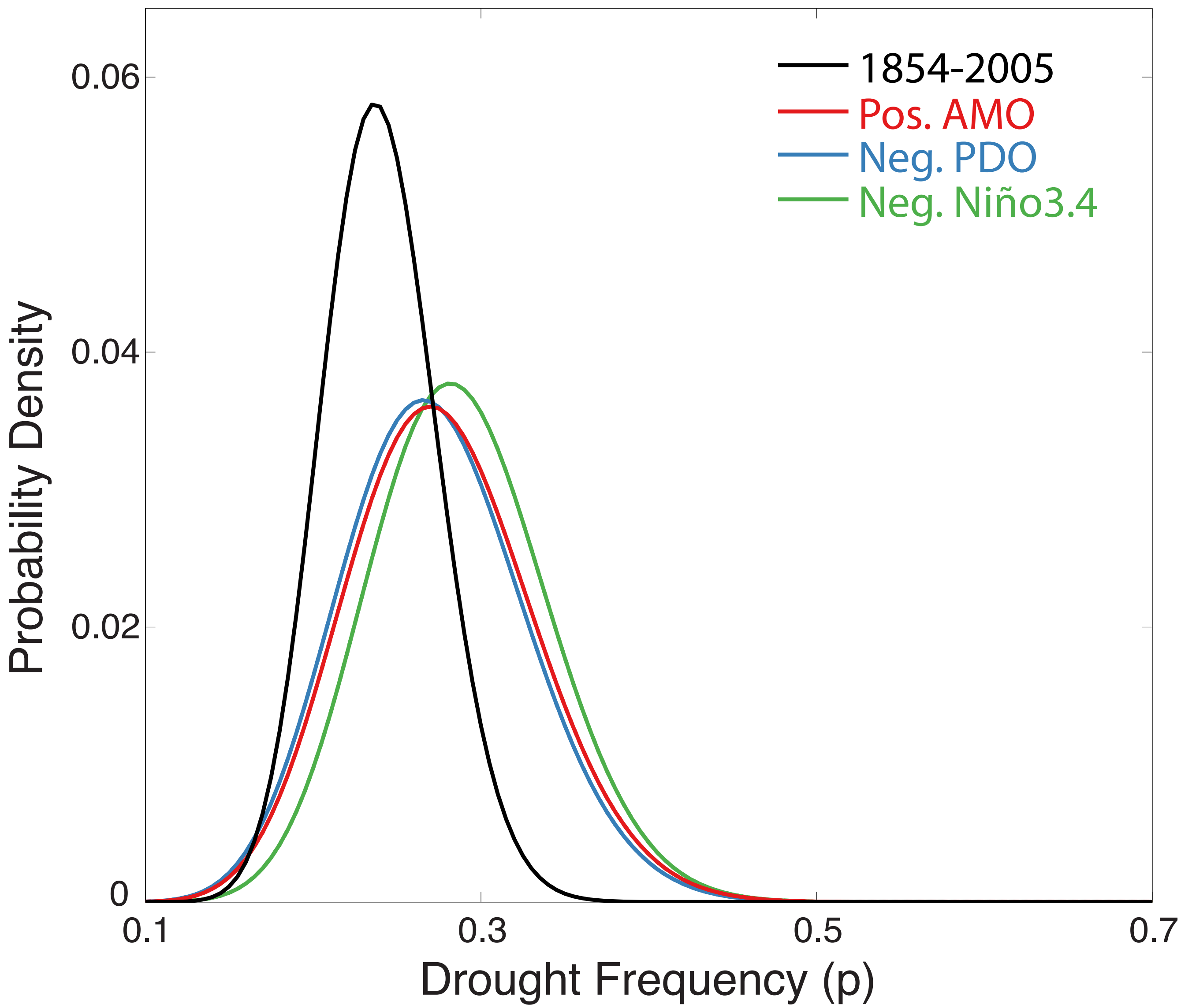

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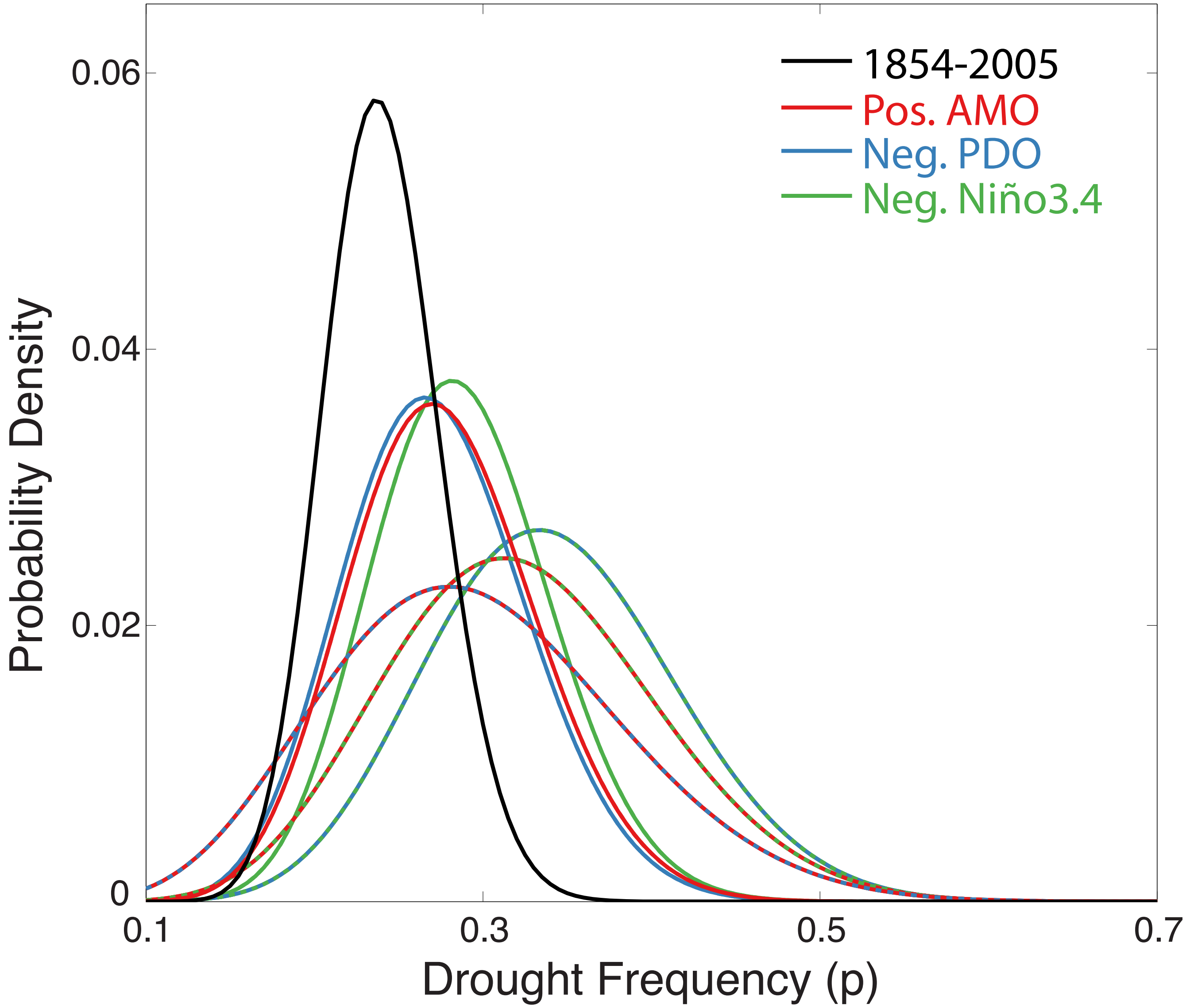
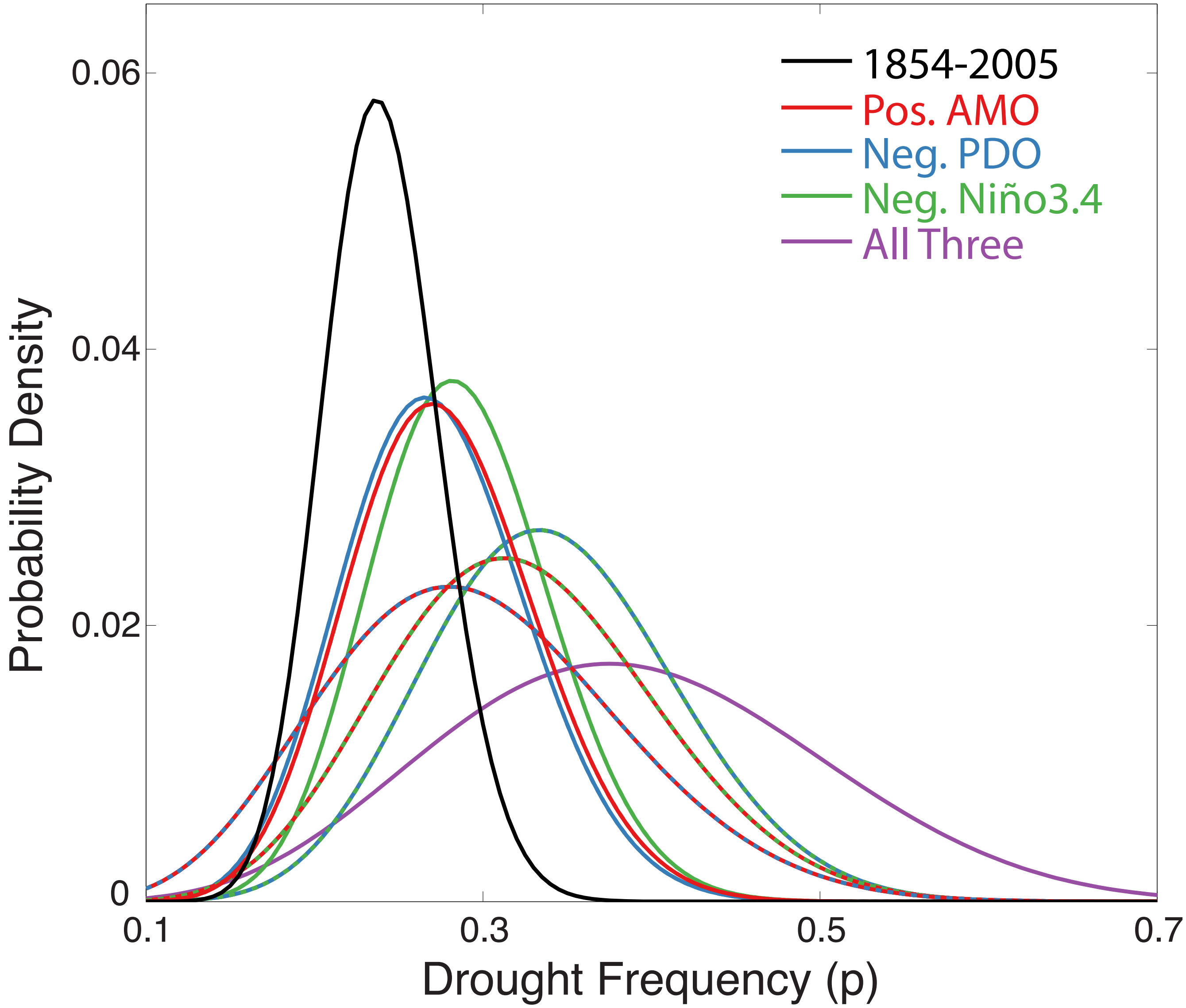


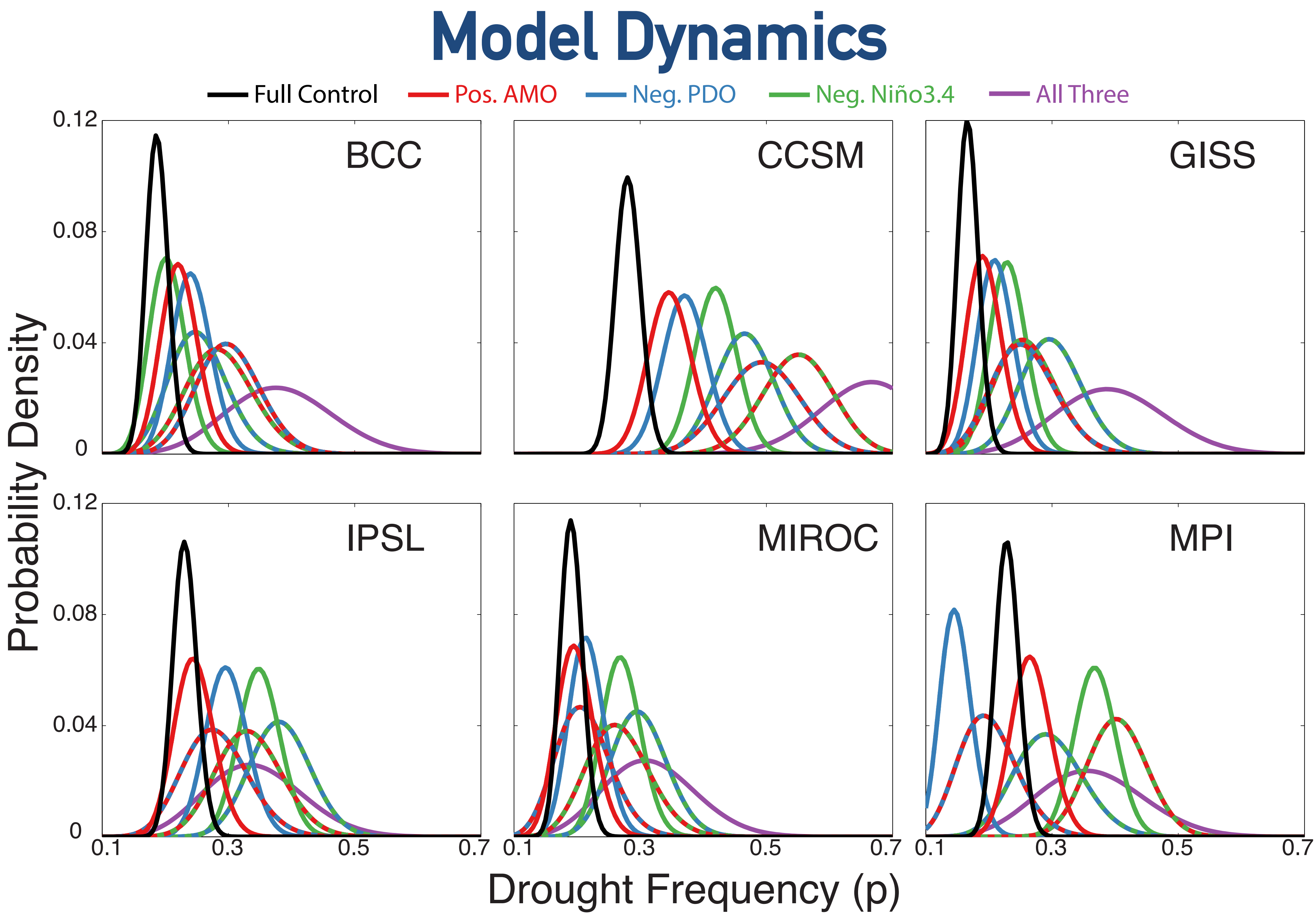
Frequency For Data Subset (Combinations)

Dynamics of Recon over Instrumental Interval

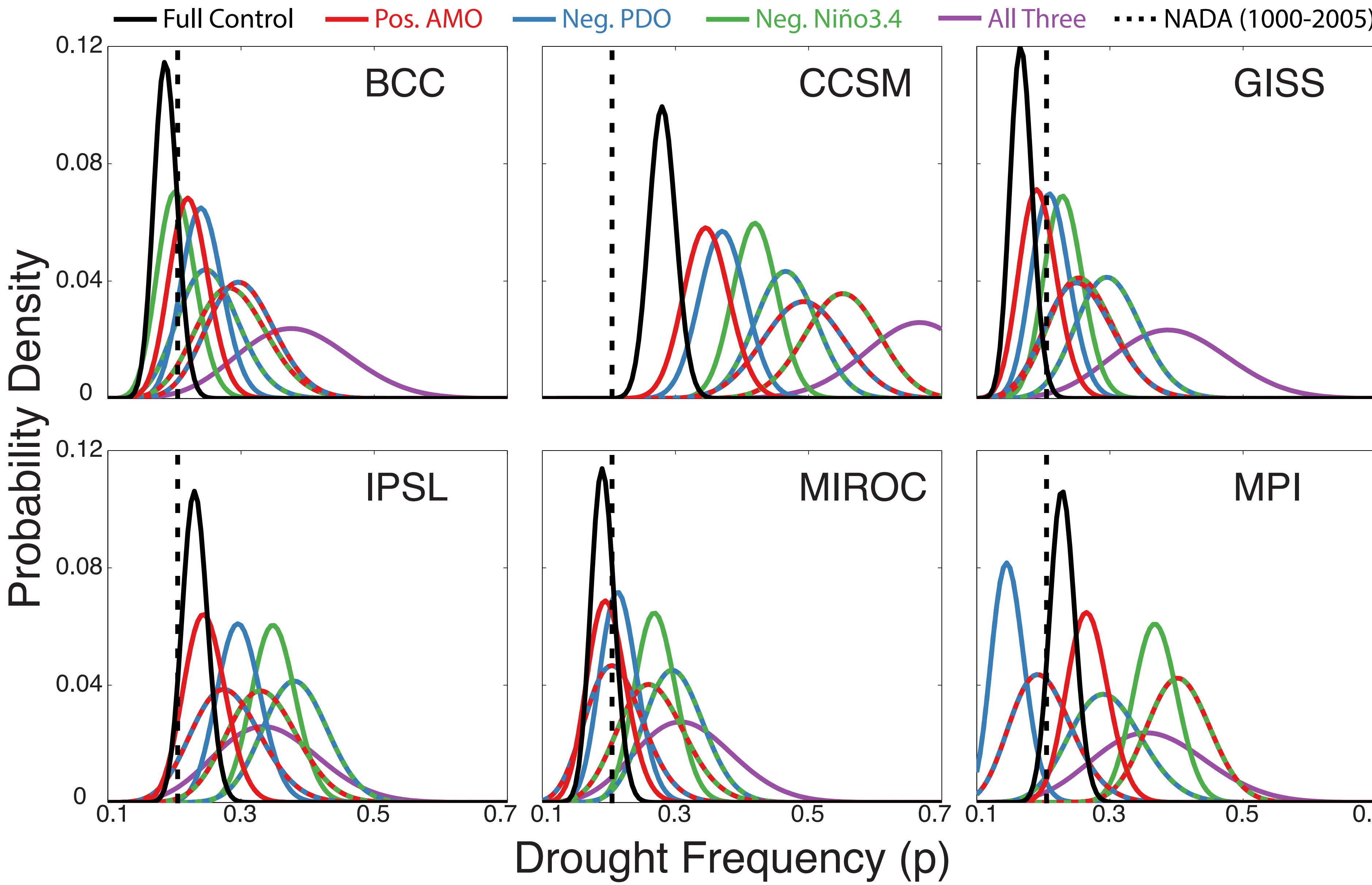


Frequency For Data Subset (Combinations)

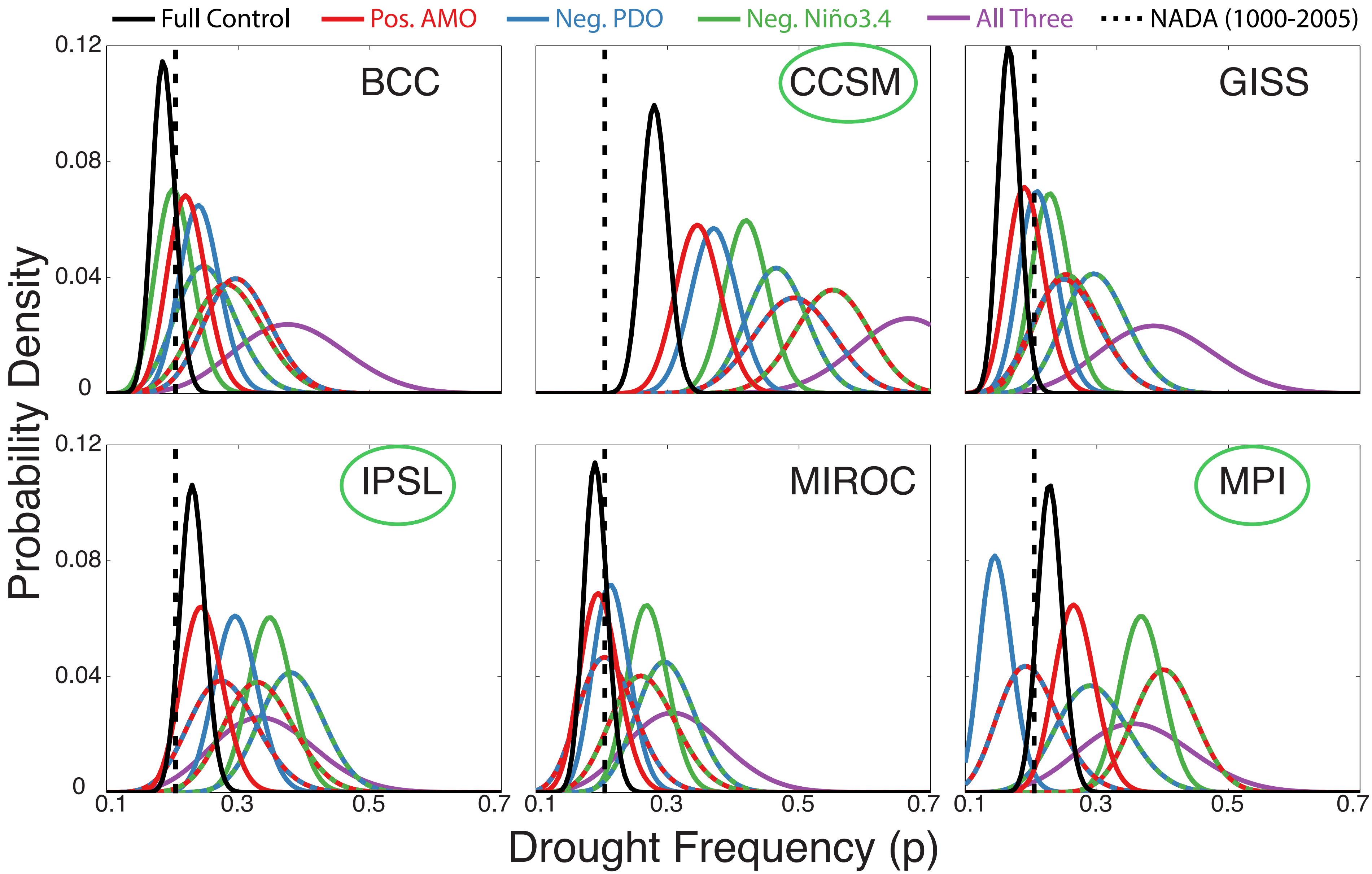
(-) PDO and ENSO, (+) AMO gives PC Drought 40% of time


Model Dynamics
Full Control
Pos. AMO
Neg. PDO
Neg. Niño3.4
All Three
BCC
CCSM
GISS
IPSL
MIROC
MPI
Probability Density
0
0.04
0.08
0.12
0.1
0.3
0.5
0.7
Drought Frequency (p)

Model Dynamics



Model Dynamics



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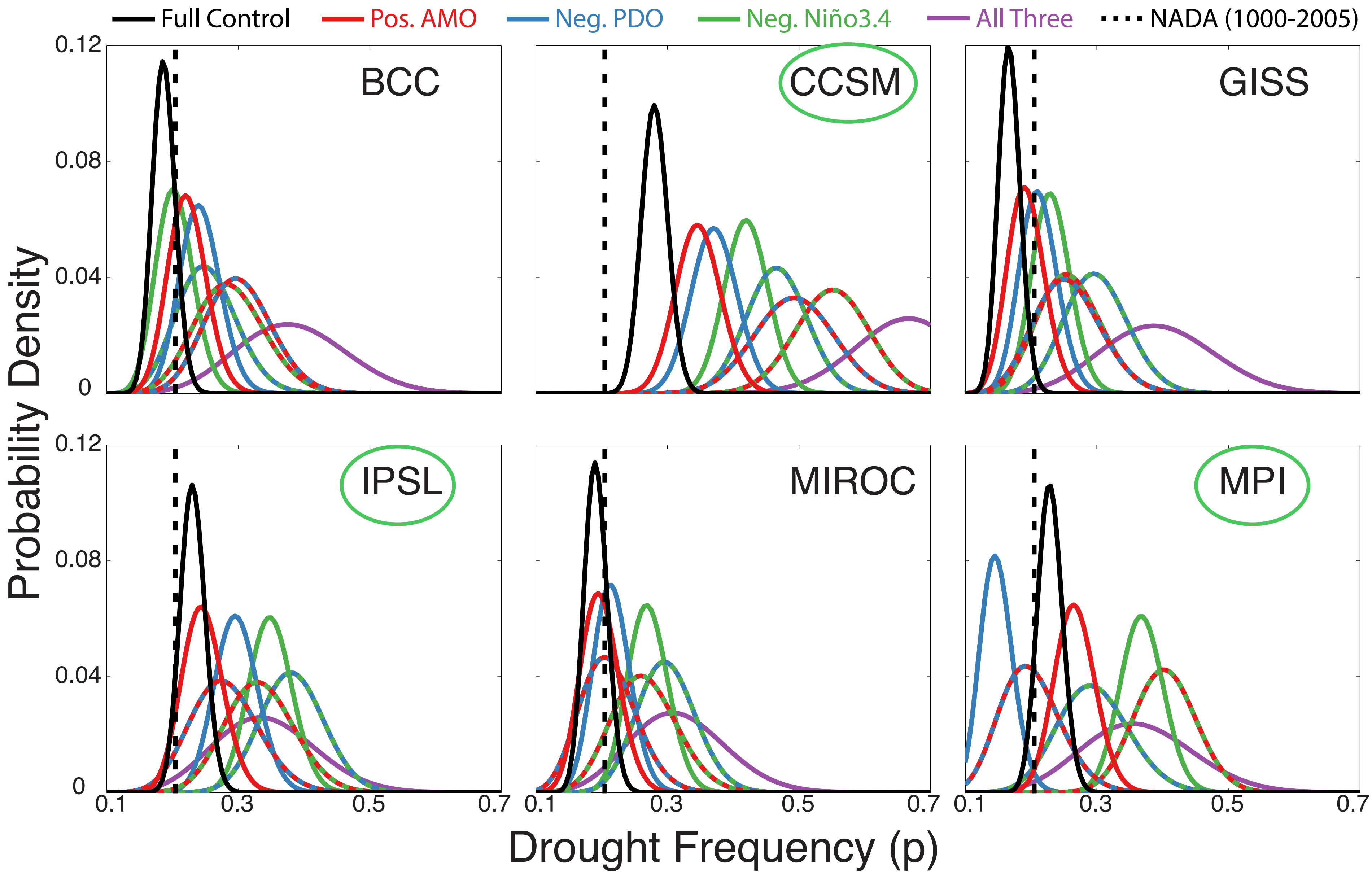
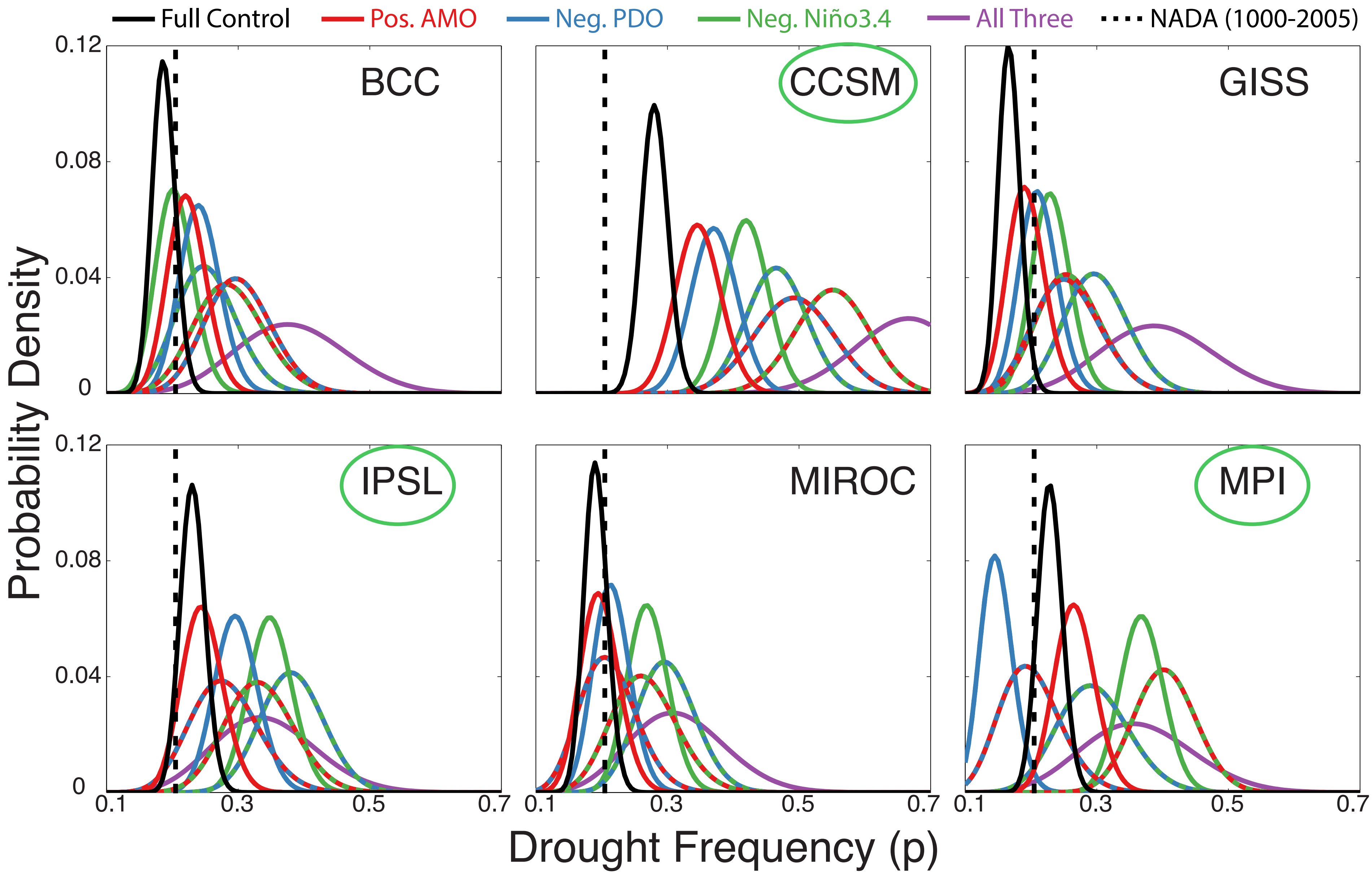


Overly strong ENSO for too much PC drought

Model Dynamics



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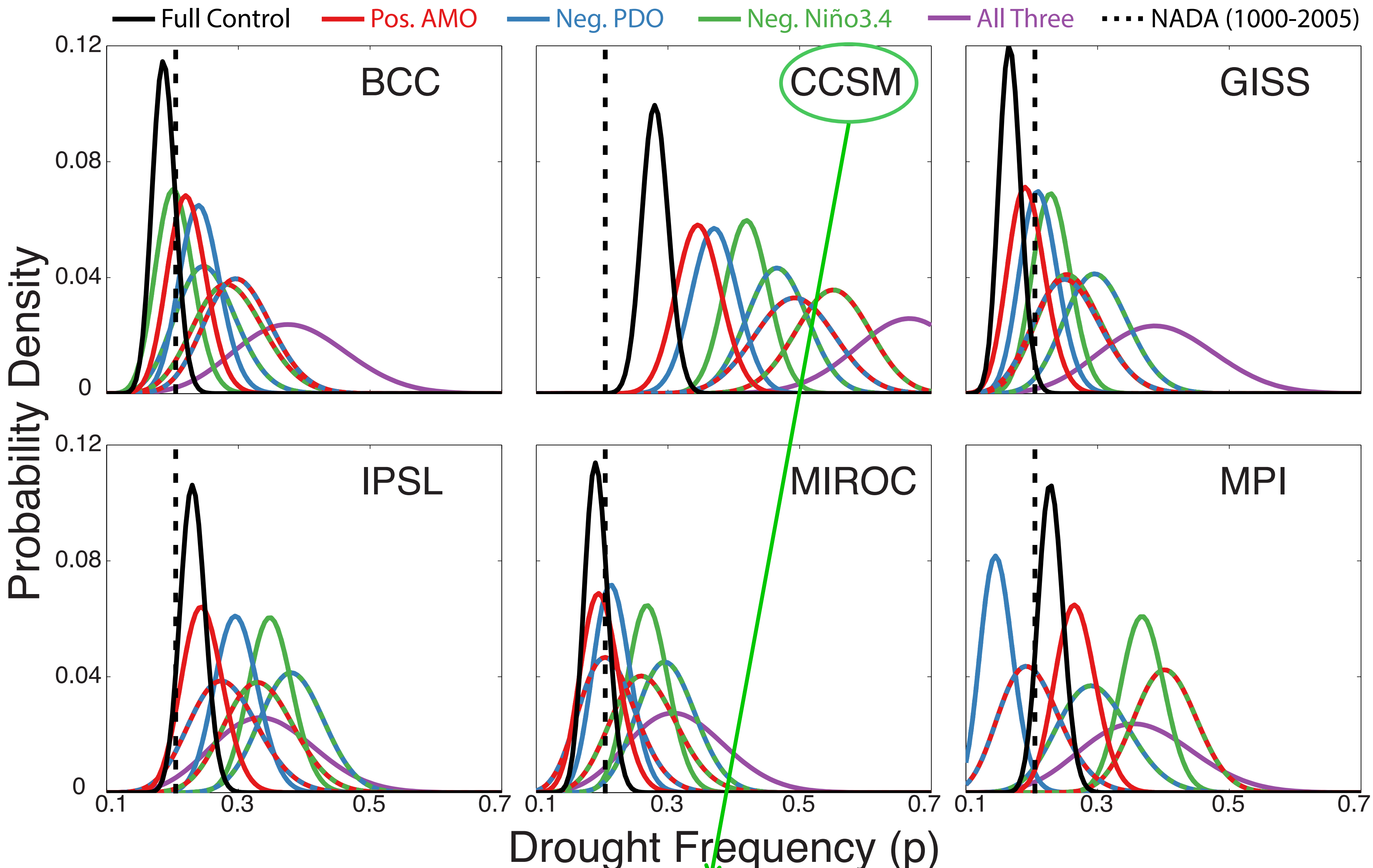
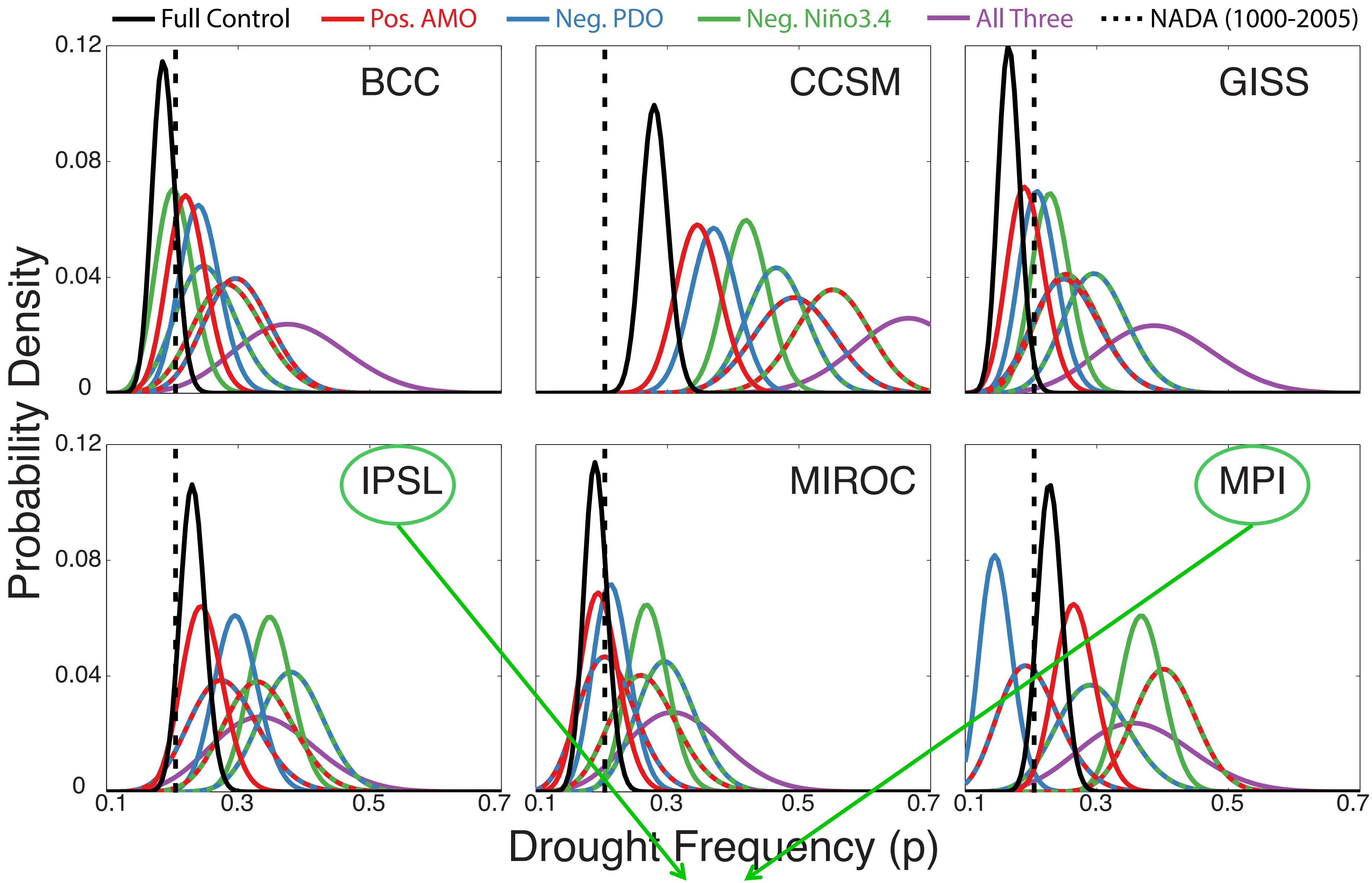


Too much ENSO variance

Model Dynamics



ENSO teleconnection pattern too homogenous over NA

Conclusions: PC Drought

- Models largely capture the characteristics and statistics of PC drought.
- ENSO is most dominant dynamical driver.
- Different models simulate PC drought in different ways depending on specific model characteristics.

Conclusions: Overarching

- No real role for exogenous forcing in simulated hydroclimate variability during C.E.
- Different models simulate hydroclimate features in different ways depending on specific model characteristics.
- Need better records of the atmosphere-ocean state during the Common Era to determine if any model dynamics are realistic.