Paleoclimate Model-Data Comparisons of Hydroclimate over North America

Sloan Coats
PAGES2k-PMIP3 Hydroclimate
Jason E. Smerdon, Benjamin I. Cook, Richard Seager, and Ed R. Cook
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

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)
North American Drought Atlas (NADA)
North American Drought Atlas (NADA)

Megadroughts
North American Drought Atlas (NADA)

Megadroughts

Years

 Instrumental interval (1871-2015 C.E.)
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?

Exogenous
- Trace Gasses
- Solar
- Volcanic

SST Boundary
- ENSO
- PDO
- AMO
Underlying dynamics?

Exogenous
- Trace Gasses
- Solar
- Volcanic

SST Boundary
- ENSO
- PDO
- AMO
Underlying dynamics?

Exogenous
- Trace Gasses
- Solar
- Volcanic

SST Boundary
- ENSO
- PDO
- AMO

Tropical Pacific
Rank droughts by persistence and severity
Rank droughts by persistence and severity

NADA American West PSDI
Paleoclimate Model-Data Comparisons

Paleoclimate estimated drought variability
Paleoclimate Model-Data Comparisons

North American Southwest Average PDSI

MODELS

BCC
CCSM
GISS
IPSL
MPI
NADA

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

Percent Occurrence During Megadroughts

- La Niña-like
- El Niño-like

Not Significant
Significant at 95% level
(Schrieber and Shmitz, 2000)
Multi-Model Dynamical Diagnostics

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

(Schrieber and Shmitz, 2000)
What about models?

- Do models simulate megadroughts?

- Is there a role for the tropical Pacific?
What about models?

- Do models simulate megadroughts?
  - CCSM does

- Is there a role for the tropical Pacific?
  - 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

<table>
<thead>
<tr>
<th>Flavor</th>
<th>Events over PDO, AMO and ENSO record</th>
</tr>
</thead>
<tbody>
<tr>
<td>SW+CP+SE</td>
<td>7</td>
</tr>
<tr>
<td>SW+CP+NW</td>
<td>1</td>
</tr>
<tr>
<td>SW+NW+SE</td>
<td>1</td>
</tr>
<tr>
<td>CP+NW+SE</td>
<td>5</td>
</tr>
<tr>
<td>SW+CP+NW+SE</td>
<td>6</td>
</tr>
</tbody>
</table>

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
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

Frequency PC Drought Occurrence

Probability Density

Drought Frequency (p)

1854-2005
Dynamics of Recon over Instrumental Interval

Certainty (determined by N)
Dynamics of Recon over Instrumental Interval

Drought Frequency (p)

Frequency For Data Subset

1854-2005

Pos. AMO

Probability Density

Drought Frequency (p)
Dynamics of Recon over Instrumental Interval

For Pos. AMO and Neg. PDO, the frequency distribution of drought is shown from 1854-2005.

Frequency for Data Subset
Dynamics of Recon over Instrumental Interval

Frequency for Data Subset

1854-2005
- Pos. AMO
- Neg. PDO
- Neg. Niño3.4

Probability Density vs. Drought Frequency (p)
Dynamics of Recon over Instrumental Interval

Frequency For Data Subset (Combinations)
Dynamics of Recon over Instrumental Interval

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

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
- NADA (1000-2005)

Drought Frequency (p)
Model Dynamics

Probability Density

BCC  CCSM  GISS

IPSL  MIROC  MPI

Drought Frequency (p)
Model Dynamics

Overly strong ENSO for too much PC drought
Model Dynamics

Overly strong ENSO for too much PC drought
Model Dynamics

- BCC
- CCSM
- GISS
- IPSL
- MIROC
- MPI

**Probability Density**

- Full Control
- Pos. AMO
- Neg. PDO
- Neg. Niño3.4
- All Three
- NADA (1000-2005)

**Drought Frequency (p)**

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.