The Role of Paleo-Drought Atlases in Climate Change Research

Edward R. Cook
Tree-Ring Laboratory
Lamont-Doherty Earth Observatory of Columbia University

Climate Change: Recent Discoveries and Future Challenges
Abrupt Climate Change in a Warming World (ACCWWW) Symposium
Lamont-Doherty Earth Observatory
Columbia University|Earth Institute
21-23 May 2013
We must better understand the causes of hydroclimatic variability over the *Common Era*, i.e. the past 2,000 yrs.

Climate models project that subtropical drying is likely to occur due to greenhouse warming and this may be happening already in the American Southwest.

**Why Paleo-Drought Atlases?**

Changes are annual means for the period 2080–2099 relative to 1980–1999

Figure courtesy of IPCC
Yet, **ominously** we now know that droughts of unprecedented severity and duration occurred in the American West and elsewhere long before rising atmospheric CO$_2$. Thus, these past **megadroughts** must be viewed as “natural” phenomena.

Knowing how such “natural” megadroughts occurred in the pre-industrial low-CO$_2$ era is necessary for predicting how likely future megadroughts in the ‘Anthropocene’ will be.
But hydroclimatic variability is a complex spatiotemporal process to model. Its spatial complexity is apparent in maps of the recent “Turn of the 21st Century Drought” in the United States. Many realizations are needed to fully characterize it, and they must include earlier megadroughts during the Common Era not present in the instrumental records.
To this end, the **North American Drought Atlas (NADA)** was developed and released to the public in 2004.

U.S. NOAA sponsored project: NA06GP0450

“Reconstruction of drought and streamflow over the coterminous United States from tree rings, with extensions into Mexico and Canada”
What are Paleo-Drought Atlases produced from?

To produce *paleo-drought atlases* with the necessary spatio-temporal resolution, we use grids of instrumental drought data (e.g. *PDSI*) and networks of annual *tree-ring chronologies*.

**Point-By-Point Regression (PPR)** is then used for reconstruction.

**PPR**: *Sequential fitting* of single grid point principal component regression models over a grid.
What can the NADA be used for?

Documenting and Mapping Large-Scale Megadroughts

Revealing Long-Term Aridity Changes in the Western U.S. since AD 800

Adapted from Cook et al., 2004
What else can the NADA been used for?

Target fields For Testing Hypothesized Causes Of Drought

“Tropical Pacific Forcing of North American Medieval Megadroughts: Testing the Concept with an Atmosphere Model Forced by Coral Reconstructed SSTs” (Seager et al., 2008, *J. Climate*)

Coral-Reconstructed Tropical Pacific SSTs (5°N-5°S, 180°-90°W) Used As Forcing

Figures from Seager et al., 2008
One Last NADA Example
(There are many more that could be shown)

Suggested Links Between Droughts And Cultural Disasters

“Great Pueblo Drought”
Overpopulation/Overexploitation
Of Natural Resources
Social System Collapse
(Douglass, 1929)

“El Año de Hambre”
Famine and Disease Kill 300,000
“Most disastrous single event in the
history of colonial maize agriculture”
(Gibson, 1964)

Figures courtesy of David Stahle
Another paleo-drought atlas: the Monsoon Asia Drought Atlas (MADA)

U.S. National Science Foundation sponsored project: ATM04-02474
“Tree-Ring Reconstructions of Asian Monsoon Climate Dynamics”

As with the NADA, a grid of instrumental drought indices and a network of annual tree-ring chronologies were used to produce the MADA.

An ensemble version of Point-By-Point Regression was used for reconstruction. See Cook et al. (2010) for details.

From Cook et al., 2010
What can the MADA be used for?

Mapping ‘Historical’ Monsoon Failures in Full Spatial Detail

“Asian Monsoon Failure and Megadrought During the Last Millennium”
(Cook et al., 2010, Science)

From Cook et al., 2010
Another MADA Example

Megadroughts and ENSO linked to cultural demise in Southeast Asia!

“Climate as a Contributing Factor in the Demise of Angkor, Cambodia”
(Buckley et al., 2010, Proc. Nat. Acad. Sci.)

Correlations between SE Asia drought and SSTs

From Buckley et al., 2010
Using MADA for data/model comparisons

“The Influence of Volcanic Eruptions on the Climate of the Asian Monsoon Region” (Anchukaitis et al., 2010, Geophy. Res. Lett.)

Superposed Epoch Analysis: MADA vs. CSM 1.4

Three published key year lists.

Almost opposite results. Who’s right? I’ll bet on the trees because they were there!
So what about trans-Pacific Basin teleconnections between Asia and North America with global SSTs as the bridge? -- Large-scale comparisons of the MADA and NADA --

Correlation of PC time series from Interdecadal Pacific Oscillation (IPO) with 13-year low-pass filtered land precipitation (1901-2000).

(from Meehl and Hu, 2006, J.Clim)
Comparisons of MADA and NADA and DJF SSTs for Two Great El Niños in 1876-1878 and 1918-1919

Overall patterns of *dry over Asia* and *wet over North America* are consistent with expectation, but the spatial details differ in ‘non-canonical’ ways, due perhaps to differences in non-tropical Pacific SSTs.
Future Paleo-Drought Atlases: the “Old World Drought Atlas” (OWDA)

U.S. NOAA sponsored project: NA10OAR4310123
"Towards Near-global Reconstruction and Understanding of Hydroclimate Variability and Change Over the Past Several Centuries”
(E. Cook, R. Seager, Y. Kushnir, P.I.s)
Drought in the ‘Old World’: the Present

1950-2002

Large-scale drying

Summer Moisture Variability across Europe
G. van der Schrier
K. R. Briffa, P. D. Jones, and T. J. Osborn
J. Climate 19, 2006
Tegel Northeast France QUSP RCS Chronology & SPEI12 Correlations

Northeast France QUSP RCS Chronology

corr Jun–Aug averaged Tegel Northeast France QUSP with Jun–Aug averaged CSIC SPEI 12 (diff) 1903:1979 p<10%
Southern Finland Samuli PISY RCS Chronology & SPEI12 Correlations

Southern Finland Samuli PISY RCS Chronology

Index

Year

corr Jun-Aug averaged Finland Samuli PISY
with Jun-Aug averaged CSIC SPEI 12 1902:1979 p<10%

corr Jun-Aug averaged Finland Samuli PISY
with Jun-Aug averaged CSIC SPEI 12 (diff) 1903:1979 p<10%
PPR applied to reconstruct the OWDA

- 595 June-July-August scPDSI grid points reconstructed from a network of 57 tree-ring chronologies
- 500 km search radius (e-folding) used to locate tree rings (expanded dynamically by 50 km increments where necessary)
- Calibration period: 1928-1978; Validation period: 1901-1927
- Year t, t+1 tree rings used as predictors
- Tree rings weighted by power of correlation with scPDSI
- AR and no AR modeling of tree rings used
- Total of 16 ensemble members produced (8 AR, 8 no AR)
- Results shown for 16 member ensemble mean
At this preliminary stage of development, all I will show you now are some analyses of the large-scale structure of the OWDA through varimax rotated EOF analysis:

Common period at all grid points: 1200-1978
OWDA Eigenvalue Trace
Analysis Period: 1200-1978

48.6%

Eigenvalue
Brokenstick*
-2SE Limits*

*Girshick, 1939, Annals of Statistics -- $\lambda \pm (2/N)^{1/2}$
OWDA Varimax Rotated EOFs

REOF 1: 18.3%

REOF 2: 12.6%

REOF 3: 12.2%

REOF 4: 5.6%
So what do the rotated EOFs and their scores mean in terms of large-scale drought variability over the OWDA domain?
OWDA Varimax Rotated EOFs and Their Correlations with JJA SPEI12 Analysis Period: 1902-1978

REOF 1: 18.3%  
SPEI12 Correlations (p<0.10)

REOF 2: 12.6%
SPEI12 Correlations (p<0.10)

REOF 3: 12.2%
SPEI12 Correlations (p<0.10)

REOF 4: 5.6%
SPEI12 Correlations (p<0.10)

SPEI12 maps courtesy of KNMI Climate Explorer
Correlations between OWDA RPC 1 Scores and 20thC Reanalysis Dec-Mar SLP: 1878-1978

RPC 1 Scores: 18.3%

Normalized Units

Wet North
Dry South
Dry North
Wet South

Year

SPEI12

Reanalysis SLP

Low

High
Correlations between OWDA RPC 1 Scores and 20th C Reanalysis Dec-Mar SLP: 1878-1978

- Wet North
- Dry South
- Dry North
- Wet South

Low NAO Index Periods?
Correlations between OWDA RPC 2 Scores and HadISST1 Jan-Apr SST: 1871-1978
Correlations between OWDA RPC 3 Scores and HadISST1 Mar-Jun SST: 1871-1978

 RPC 3 Scores: 12.2%

SPEI12

Wet
Dry

HadISST1

Wet
Dry

Correlation

-0.6  -0.5  -0.4  -0.3  -0.2  0.2  0.3  0.4  0.5  0.6
Correlations between OWDA RPC 4 Scores and HadISST1 Sep-Dec SST: 1871-1978

<table>
<thead>
<tr>
<th>Wet South</th>
<th>Dry North</th>
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<tbody>
<tr>
<td>Dry South</td>
<td>Wet North</td>
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SPEI12: SPEI12 Dry, Wet

HadISST1: HadISST1 Cool
Concluding Remarks

- The value of paleo-drought atlases to climate change research is clear. Tree rings lead the way in this regard.

- This applies to the **NADA**, the **MADA**, and now the soon to be finished **OWDA**. Preliminary results shown here indicate the great potential of **OWDA** as a climate change research tool.

- The first version of **OWDA** will be ready for publication and release sometime later this year. It will cover the past 1000-2000 years.

- Future drought atlases are planned for South America (the **SADA**) and Australia (the **AUDA**) – if I live long enough (**I plan to live many more years!**) and pending available funding (**A much greater uncertainty!!!**).

- This would provide a **near-global** land reconstruction of hydroclimatic variability over the past millennium.

Thank you!