Multidecadal Climate Variability

Signal Propagation across the Northern Hemisphere

2012
Marcia Glaze Wyatt
How Something is Viewed Determines What Can be Seen!
How well can we understand a system by “viewing” only its parts?

A network’s ultimate expression is not merely a sum total of its parts.
Viewing Climate as a Network

Network = a collection of interacting “parts”
In its simplest form, a network is a collection of nodes joined by edges.

*Physics Today* Nov ‘08
Each Node = Self-Sustained “Oscillator”

Self-sustained Oscillators Can be Synchronized
SYNCHRONIZATION

Individual Self-Sustained “Oscillators”
Interact
Adjust
Share Tempo
Self-Organizing
Network of “Parts” are self-sustained oscillators with local coupling between oscillators.

COMMUNICATION STABILITY

SELF-ORGANIZING

“Parts” are self-sustained oscillators

ADD

Local coupling between oscillators

SIGNAL PROPAGATION
Beyond Synchrony

“Stadium-Wave Signal”
Local Coupling $\rightarrow$ Signal Propagation
Hypothesis

Climate as a Stadium Wave:

Propagation of a low-frequency climate-signal through a network of atmospheric, Ice, and oceanic self-sustained oscillating indices
Data Sets for testing the Stadium-Wave Signal

Instrumental data
20th century

Proxy data
1700-2000

CMIP3 model data
20thc
Pre-industrial
Methods

DJFM all indices

**STEP ONE:**
20thc

**STEP TWO:**
Proxy
1700-2000

**STEP THREE**
Modeled
20thc
pre-ind

1st Order
Linearly Detrend
13y Smooth

2nd Order
M-SSA
Significance Tests

3rd Order
M-SSA
Correlations
Significance Tests

**STEP ONE:**
“original 8”

“complementary 7”

“extended data set”

“dynamic” proxies

“conventional” proxies

CMIP3 data

“document”

“mechanism”

“history”

“signal simulation”
Methods
DJFM all indices

1st Order
Linearly Detrend
13y Smoothed

“original 8”

Indices:
NHT, AMO, AT, NAO,
NINO3.4, NPO, PDO, ALPI

STEP ONE:
20thc

Indices:
NHT, AMO, AT, NAO,
NINO3.4, NPO, PDO, ALPI
“Real Time” timeseries:
+NHT, -AMO, NAO, NPO, PDO
Random Red-Noise? or Coherent Signal?

-AMO (4y) +NAO (8y) +PDO (4y) +ALPI

• Lagged correlations of multidecadal signal in various indices

• Conclude possibility of signal

• Need tool that detects lagged relationships
**Methods**

DJFM all indices

**STEP ONE:**

20thc

- 1st Order
  - Linearly Detrend
  - 13y Smooth

- 2nd Order
  - M-SSA
  - Significance Tests

- "original 8"
  - NHT, AMO, AT, NAO, NINO3.4, NPO, PDO, and ALPI
  - detrended & normalized prior to processing

**Multichannel Singular Spectrum Analysis**

Propagating Signals

1) Individual Time Series Extended
2) Covariance Matrix
3) Shared Variability
4) Plot means of mode variance
M-SSA Plots

(a) Fraction of variance (%) $M=20$

(b) Cumulative variance (%) $M=20$

Random variance unlikely for this leading pair; upper red dashed line outlines the corresponding surrogate spectra generated by red-noise model.
RCs for Modes of Variability

Rc1

Rc2

Rc3

Rc4

1900 1950 2000

-1 0 1

1900 1950 2000

-1 0 1

+
Climate as a “Stadium Wave”

Normalized reconstructed components 1-2

Indices

Time (yr)

-2

-1.5

-1

-0.5

0

0.5

1

1.5

2

1900 1920 1940 1960 1980 2000

-NHT
-AMO
AT
NAO
NINO3.4
NPO
PDO
ALPI
**Methods**

DJFM all indices, where possible

**STEP ONE:**

20thc

mechanism

20thc

document

**1st Order**
Linear Detrend
13y Smooth

“original 8”

“complementary 7”

**2nd Order**
M-SSA
Significance Tests

**3rd Order**
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Significance Tests

“extended data set”

Eurasian Arctic

PCI

SST dipole

Added indices

Added indices
Ocean-Ice-Atmosphere Interactions

Ocean-Eurasian Arctic Ice-Wind Relationships (M-SSA RCs of combined modes 1&2)
Methods

STEP ONE:
- 20thc
- document
- mechanism

STEP TWO:
- 1700-2000
- history

1st Order
- Linear Detrend
- 13y Smooth

2nd Order
- M-SSA
- Significance Tests

3rd Order
- M-SSA
- Correlations
- Significance Tests

3rd Order
- M-SSA
- Correlations
- Significance Tests

“original 8”
“complementary 7”
“extended data set”

“conventional” proxies
- Tree rings
- Isotope ratios from ice, corals
- Historical documentation
“Conventional” Proxy Replacements 1900 to 2000

M-SSA RCs of leading modes one & two
Proxy Replacements 1900-2000

- NHT (Jones)
- AMO (Gray)
- NAO (Luthebacher)
- PDO (Shen)

Statistically Significant p<5%
Proxy Replacement 1700 to 2000
M-SSA RCs of leading modes one and two

Not significant at p<5%
Methods

DJFM all indices

STEP ONE:
20thc

STEP TWO:
1700-2000

STEP THREE
20thc pre-ind

1st Order
Linear Detrend
13y Smooth

2nd Order
M-SSA
Significance Tests

"original 8"

3rd Order
M-SSA
Correlations
Significance Tests

"complementary 7"

"extended data set"

3rd Order
M-SSA
Correlations
Significance Tests

"conventional" proxies

CMIP3 data
<table>
<thead>
<tr>
<th>RC Number</th>
<th>Group</th>
<th>Periodicity</th>
<th>Model</th>
<th>Experiment</th>
<th>Run</th>
<th>Significant with Annual Sampling</th>
<th>Significant with Sampling @ 5y Running Mean</th>
<th>Comments Related to Signal Propagation or Other Behavior</th>
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<tbody>
<tr>
<td>1</td>
<td>single</td>
<td>~70y</td>
<td>CCCMA_cgcm3</td>
<td>20c</td>
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<td>no</td>
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<tr>
<td>1,2</td>
<td>pair</td>
<td>bi-annual</td>
<td>CNRM_cm3</td>
<td>20c</td>
<td>1</td>
<td>yes</td>
<td>no</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>single</td>
<td>~25y</td>
<td>CNRM_cm3</td>
<td>20c</td>
<td>1</td>
<td>yes</td>
<td>no</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>single</td>
<td>subdecadal</td>
<td>CSIRO_mk3</td>
<td>20c</td>
<td>1</td>
<td>yes</td>
<td>no</td>
<td></td>
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<tr>
<td>5</td>
<td>single</td>
<td>subdecadal</td>
<td>CSIRO_mk3</td>
<td>20c</td>
<td>1</td>
<td>yes</td>
<td>no</td>
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<td>6,7</td>
<td>pair</td>
<td>bi-annual</td>
<td>CSIRO_mk3</td>
<td>20c</td>
<td>1</td>
<td>yes</td>
<td>no</td>
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<tr>
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<td>~70y</td>
<td>CSIRO_mk3</td>
<td>20c</td>
<td>1</td>
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<td>yes</td>
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<td>pair</td>
<td>~35y</td>
<td>*GFDL_2_0</td>
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<td>1</td>
<td>marginal</td>
<td>yes</td>
<td>no propagation</td>
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<td>pair</td>
<td>~35</td>
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<td>20c</td>
<td>3</td>
<td>no</td>
<td>marginal</td>
<td>no propagation</td>
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<td>~60y</td>
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<tr>
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<td>~60y</td>
<td>MIUB_echo_g</td>
<td>20c</td>
<td>2</td>
<td>yes</td>
<td>no</td>
<td></td>
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<tr>
<td>3</td>
<td>single</td>
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<td>MIUB_echo_g</td>
<td>20c</td>
<td>2</td>
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<td>~55</td>
<td>UKMO_hadcm3</td>
<td>20c</td>
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<td>marginal</td>
<td>no</td>
<td></td>
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<tr>
<td>1</td>
<td>single</td>
<td>~50y</td>
<td>CNRM_cm3</td>
<td>control</td>
<td>1</td>
<td>no</td>
<td>marginal</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>single</td>
<td>~25y</td>
<td>CSIRO_mk3</td>
<td>control</td>
<td>1</td>
<td>no</td>
<td>yes</td>
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<td>single</td>
<td>~55 to 75y</td>
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</tr>
<tr>
<td>2</td>
<td>single</td>
<td>~25y</td>
<td>GFDL_2_0</td>
<td>control</td>
<td>1</td>
<td>n/a</td>
<td>yes</td>
<td></td>
</tr>
</tbody>
</table>
Summary

• **Hypothesis**: Low-frequency climate signal propagates across NH

• **Tested**: M-SSA cornerstone of analysis techniques
  – 20th century Instrumental Data
    • Documentation of Signal
    • Explore Mechanism
  – Proxy Data: 1700-2000
    • Probe History
  – CMIP3 Model-Generated Data: 20thc and pre-industrial
    • Model Reproduction?

• **Results**:
  – A statistically significant low-frequency climate signal propagates through network of indices 20thc
    • Ocean-ice-atmospheric coupling
  – Proxies show signal: 1850 (significant) and to 1700 (with statistical uncertainty)
  – Models do not reproduce signal
Interpretation/Thoughts

• **Step One 20\textsuperscript{th} Century Instrumental Data**
  • Statistics can not “prove”.
  • Need mechanism.
  • Literature support for “links”
    – Highlight deep, interactive ocean
    – COA position, migration
    – Western-boundary currents/extensions

• **Step Two: 1700-200 Proxy Data**
  • Not statistically significant prior to 1850:
    – Could mean no signal
    – Could mean proxy data too noisy

• **Step Three: model-generated Data**
  – No signal with statistical significance, frequency, or propagation characteristics of stadium-wave signal
  • Critical links not well-modeled:
    – COAs
    – Sea-ice, especially motion and export
    – Western-boundary currents
Outstanding Questions:

• What explains the signal’s absence of statistical significance in proxy data prior to 1850?

• Does sea ice influence the climate signal’s sensitivity?

• Why do models not simulate the signal?
Signal Propagation & Synchronized Networks

THE END
Miscellaneous Extras follow
Channel-Fraction of Raw-Index Variance

Channel-variance fractions due to M-SSA 1&2

How much variability in an index can be “explained” by the M-SSA signal?
7 Indices added to Index Network
Using Alternate Proxy Data: 1700-2000
Running Conclusion
(Step One: 2\textsuperscript{nd} order analysis)

- **Statistical Results**
  - Climate signal documented
  - Significance 95%

- **Speculation**
  - Tempo
  - Feedback

- **Cautionary Note**

- **Next Step:**
  - Explore Mechanism
**Methods**

DJFM all indices, where possible

**STEP ONE:**

20thc

**mechanism**

**document**

1**st Order**
Linear Detrend
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“extended data set”

**Added Indices:**

Arctic T

Eurasian Arctic Shelf sea ice

Atlantic SSTA Dipole

Pacific Circulation Index (PCI),
Channel-Fraction Variance of Select Indices from Original plus Arctic Variables and Dynamic Proxies
Running Conclusion:
(Step One: 3rd order analysis)

• Eurasian Arctic Sea Ice
  – Relationship with Atlantic
  – Relationship with Winds

• ITCZ Migrations
  – Max NHT, Min Sea Ice, North ITCZ
  – Min NHT, Max Sea Ice, South ITCZ

• Pacific feedback to Atlantic
  – Pacific Anomaly Trend and AMO

• Next Step:
  – Probe History
Running Conclusion
(Step Two: 3rd order analysis)

• 20thc stadium wave  
  – All proxies

• 1850-2000  
  – Significant (not shown)

• Prior to 1850  
  – "Signal", yet amplitude, frequency modifications  
  – Significance not identified  
    • No signal? Or diminished quality of proxy data? Or other?

• Next Step:  
  – Model-Data Simulations
Running Conclusion
(Step Three: 2\textsuperscript{nd} order analysis)

• No stadium wave signal in Model Data

• Speculation on reason
  – Signal could be random
  – Models could have deficiencies
    • Sea-ice
    • COAs
    • Western-boundary currents