MODES OF VARIABILITY IN OBSERVED NEAR SURFACE TEMPERATURES

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Motivation
The global-mean near-surface temperature record I

To note:
- Overall warming trend
- High frequency variability
- Not much change during first 50 years
- Increase in T from beginning of 20th century to about 1944
- T stays the same or slight cooling from 1944 to 1976
- Rising T from 1976 onwards

Due to an oscillation of period 60-80 years ??
Motivation

The global-mean near-surface temperature record II

= human-induced climate change + natural variability

In order to make accurate future climate projections on which to base decisions of how to mitigate and adapt to future climate, we need to be able to separate the human-caused climate change from the natural variability.

Study natural variability!
Spectral Analysis

- **Fourier Analysis**
  - Uses simple oscillating functions, namely *sines and cosines* as basis functions.
  - **Disadvantages:**
    - It is hard to capture long period oscillations that have wavelength in the order 1 to 0.5 of the record length.
    - Almost impossible to achieve statistical significance for short time series.
    - Applicable only to detrended time series when interested in the long period oscillations.

- **Singular Spectrum Analysis (SSA)** [Broomhead and King 1986; Vautard and Ghil 1989]
  - Is not restricted to using *sines and cosines* as basis functions.
  - Rather finds the “best” basis functions.
  - An oscillatory mode is characterized by a pair of nearly equal SSA eigenvalues and associated principal components that are in approximate phase quadrature.
  - **Advantage:**
    - Possible to achieve statistical significance even for “short” time series
    - Applicable to detrended as well a not detrended time series.
Method:
SSA applied to non-detrended global and hemispheric time series.

Results:
- Trend (EVs 1 & 2)
- 3 fundamental oscillations with periods:
  - 21 years (EV pair 3 & 4)
    • global character
    • solar origin is unlikely
  - 6 years (EV pair 11 & 12)
    • Association with ENSO is likely
  - 5 years (EV pair 6 & 7)
    • Association with ENSO is likely
- No oscillation of period 60-80 years!
Previous SSA Studies II
Schlesinger & Ramankutty 1994

Method:
SSA applied to detrended global and regional time series.

Results:
- An oscillation of period 65-70 years!
  - Exists in the North Atlantic and its surrounding land regions → AMO.
  - Linked to variations in the Thermohaline Circulation.
- Found in addition:
  - An oscillation of period 22 years in Eastern Equatorial and South Pacific.
  - An oscillation of period 9 years in the Western Equatorial Pacific.

Schlesinger & Ramankutty 1994, Nature (SR94)
Use simple climate model forced by:
- Greenhouse Gases (GHGs)
- Anthropogenic-sulphate-aerosols (ASAs)

to determine what is “natural variability”.

Two parameters have to be determined:

\( \Delta T_{2x} \) – the equilibrium surface-air temperature change in response to the radiative forcing equivalent to a doubling of the CO2 concentration.

\( \Delta F_{ASA} \) – the radiative forcing due to ASA.
Detrending
\( \Delta T_{2x} \) & \( \Delta F_{ASA} \)

\( \Delta T_{2x} \) is chosen such that the root-mean-square-differences between simulated and observed global-mean temperature is minimized.

\( \Delta F_{ASA} \) is chosen such that the root-mean-square-differences between simulated and observed inter-hemispheric temperature differences are minimized.
Detrending
Observed & Simulated

Observered Temperature Record

Temperature Anomalies (°C)

1850 1875 1900 1925 1950 1975 2000

Simulated Temperature Record

Temperature Anomalies (°C)

1850 1875 1900 1925 1950 1975 2000
SR94’s AMO

When will the AMO return into its positive phase?

Cool Phase

→ Masks the GHG warming
Update of SR94 study
Observed Temperatures

Global Temperature Anomalies

Interhemispheric Difference Anomalies

Brohan et al. 2006, JGR
Update of SR94 study
Well-Mixed Greenhouse Gases

MacFarling Meure et al. 2006, GRL; Walker et al. 2000, JGR; Prinn et al. 2000, JGR
SR94 assumed an 80/20 partition.
SR94 did not consider the radiative forcing of tropospheric ozone.
Update of SR94 study

Solar Irradiance

SR94 did not consider solar forcing.

\[ \approx 0.5 \text{ W/m}^2 \]

\[ \approx 3 \text{ W/m}^2 \]
Results
so called "noise floor"

Global SSA Spectrum

SSA Spectrum

Eigenvalue

Mode

an oscillatory pair
Global SSA Spectrum

SSA Spectrum

Returned into its positive phase in 1997

an oscillatory pair

Temperature Anomalies (°C)

Eigenvalue

Year

Mode

τ = 69 years
Global SSA Spectrum

Returned into its positive phase in 1997

2nd oscillatory pair

Eigenvector

Mode

Temperature Anomalies (°C)

Year

τ = 21 years

Global SSA Spectrum
Global Power Spectrum
Statistical Significance
Allen & Smith 1996

- Assume time series does not contain any signal but is pure noise (1st order auto-correlated red noise).

- Extract noise characteristic of original time series.

- Generate 1000 surrogate time series with same noise characteristics as original one.

- Perform SSA on the 1000 surrogate time series.
Global Statistical Significance

SSA Spectrum

Eigenvalue

Mode

Year

Temperature Anomalies (°C)

O5

τ = 4 years
Global SSA Spectrum

Significant oscillation within the so-called “noise floor”

There is signal in the noise.
Regional
Definition of Regions
O1 is present in all oceanic regions, other than the Eastern Equatorial Pacific, and the land regions surrounding the North Atlantic Ocean.
O2 is present in all regions, other than the Western Equatorial Pacific.
O3 is present in both NH and SH oceanic and terrestrial regions.
O4 might stem from the **Northern Hemisphere**, possibly from Eurasia, North America, the North Pacific and the Western Equatorial Pacific.
O5 might emanate from the **Southern Hemisphere**, possibly from South America, Australia, the Eastern Equatorial Pacific and the Indian Ocean.
Discussions

We propose that the newly discovered multidecadal oscillations, namely

- The South Atlantic Multidecadal Oscillation (SAMO)
- The North Pacific Multidecadal Oscillation (NPMO)
- The Western Equatorial Pacific Multidecadal Oscillation (WEPMO)
- The South Pacific Multidecadal Oscillation (SPMO)
- The Indian Ocean Multidecadal Oscillation (IOMO)

are due to variation in the Thermohaline Circulation in their respective ocean basins.

This is consistent with O1 being absent in the Eastern Equatorial Pacific and weak in Eurasia.

This hypothesis will be tested by investigating the gridded ocean temperature fields simulated by global circulation models (PhD work).
Cause of O2

O2 and the Sun

- No mechanism!
- Fact why O2 leads the solar cycle by three years is unexplained.
- Two cycles are in phase in the 20\textsuperscript{th} century but out of phase in the 19\textsuperscript{th} century.
- O2 is not due to the magnetic hale cycle.

http://www.sidc.be/sunspot-data/
Cause of O2
O2 and the Moon

- Period of the lunar nodal cycle is 18.6 years and hence smaller than the 21 years, the dominant period of O2.

- Two signals do not correlate well ($\rho = 0.31$).

➢ O2 is not due to the lunar nodal cycle.
Cause of O3

O3 and the Sun

- Mechanism is too weak!
- Fact why O3 lags the solar cycle by one year is unexplained.
- Dominant period of the sunspot cycle is 11 years and hence larger than the 9 years, the dominant period of O3.
- Two signals do not correlate well ($\rho = 0.10$).

- O3 is not due to the sunspot cycle.

http://www.sidc.be/sunspot-data/
Cause of O3

O3 and the Moon

- Period of the lunar nodal cycle is 9.3 years and hence almost equal to 9 years, the dominant period of O3.

- Two signals do correlate well ($\rho = 0.68$).

- A relationship between O3 and the lunar nodal cycle cannot be ruled out.
Cause of O4 & O5

O4 & O5 and El Niño

- O4 is the dominant oscillation in Eurasia.
- O4 does not exist in the Eastern Equatorial Pacific.
- O5 is very weak in the Eastern Equatorial Pacific (EV = 4.1%).
- The dominant oscillation in the Eastern Equatorial Pacific has a period of 6 years and is distinct from O4 and O5.
- O4 and O5 are not related to ENSO.
Robustness of Results

Temperature Data Sets

O1 – O3 are found in all four temperature data sets.
Robustness of Results

SSA without detrending

- O1-O5 are found in both the detrended and the non detrended global temperature records.
- However, the statistical significance of the oscillation gets greatly reduced, since the trends account for more than 80% of the total variance!
- In addition the period of O1 gets reduced to 59 years.

Detrending!
Robustness of Results
SSA Window Length

O1 – O5 are found to be almost identical for different choices if the window length \( L \in \{40, 77\} \text{ years} \).
Robustness of Results
Record Length; Global

- Up until a starting year of 1910, O1 is a robust feature in the global temperature record, with very consistent amplitude, period and phase.
- The amplitude, period and phase of O2 are consistent throughout the entire test.
- Neither O1 nor O2 is an artifact of the (unreliable) early part of the temperature record.
Robustness of Results

Record Length; Regional
The early century warming and subsequent mid century cooling are predominately due to O1.

The late century warming is predominately due to input of greenhouse gases into the atmosphere by humanity.
Implications
African O1 and precipitation in Sahel region

$\tau = 79$ years

More rain in Sahel region again???

How certain am I ???

I would bet my house!
About Attribution
Attribution
Whole Period

Ring et al. 2010, submitted
Attribution
Early Century Warming

Ring et al. 2010, submitted
Attribution
Mid Century Cooling

Percentage Contributions for 1944–1976 Period

Ring et al. 2010, submitted
Attribution
Late Century Warming

Ring et al. 2010, submitted
Thank You
Conclusions

- Five significant oscillations of periods $T_1 = 69$ years, $T_2 = 21$ years, $T_3 = 9$ years, $T_4 = 5$ years and $T_5 = 4$ years are found in the global climate system.

- $O_1-O_5$ are robust features of the global temperature record.

- There can be signal in the so called “SSA noise floor”.

- Prior detrending is advisable in order to uncover significant oscillations that would be otherwise concealed by the trend.
Conclusions continued

O1 is present in all oceanic regions, other than the Eastern Equatorial Pacific, and the land regions surrounding the North Atlantic Ocean. Five “new” multidecadal oscillations namely:

- The South Atlantic Multidecadal Oscillation (SAMO)
- The North Pacific Multidecadal Oscillation (NPMO)
- The Western Equatorial Pacific Multidecadal Oscillation (WEPMO)
- The South Pacific Multidecadal Oscillation (SPMO)
- The Indian Ocean Multidecadal Oscillation (IOMO)

are discovered.
Conclusions continued

- O1 is the **major** driver behind the early century warming and the subsequent mid century cooling.
- O1 was in its **negative** phase from 1962 to 1997 and hence was masking the warming trend.
- We can expect the warming to amplify since O1 has returned into its positive phase in 1997.
- O2 is present in all regions, other than the Western Equatorial Pacific.
- O3 is present in both **NH and SH** oceanic and terrestrial regions.
Conclusions continued

- O4 might stem from the **Northern Hemisphere**, possibly from Eurasia, North America, the North Pacific and the Western Equatorial Pacific.

- O5 might emanate from the **Southern Hemisphere**, possibly from South America, Australia, the Eastern Equatorial Pacific and the Indian Ocean.
Conclusions continued

- We propose that O1 is due to small variations in the Thermohaline Circulation.
- O2 is not due to the Sun nor the Moon.
- O3 is not due to the Sun.
- O4 is not related to ENSO.
- O5 is not related to ENSO.