Decadal climate variability in the Pacific: character, causes and predictability

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Contents

- Australian tropical cyclones: interannual-decadal variability, and long-term trends and links to ENSO
- Interdecadal variability and trends in the Walker circulation, ENSO activity, and the Southern Oscillation Index (SOI)
- Predictability of ENSO teleconnections, origin of decadal ENSO-like patterns
Brisbane - 1893 flood – 23 deaths
Mackay 1918
Innisfail 1918

3500 residents, only 12 houses remained intact
Approximately 75-100 deaths
New tropical cyclone (TC) data base

- Taken over a decade to develop
- TCs and severe storms over entire NE Australia: 1858-2008
- Primary sources of information:
  - Bureau collection of detailed case histories for numerous TCs - including all TCs since mid-1950s.
  - Bureau collection of numerous bounded meteorological analyses made covering TCs back to 1890s
  - Numerous research papers
  - Reports (internal Bureau; state, local)
  - Extensive newspaper clippings held by the Bureau
  - QLD newspaper archives
  - Information held by Cairns and Townsville historical societies
  - Extensive unpublished information from the public – including photos
THE BATHURST BAY HURRICANE AND ASSOCIATED STORM SURGE

by H.E. Whittingham

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1. INTRODUCTION

There are many reasons for a closer examination of the Bathurst Bay hurricane of 5 March 1899; among them we may list the following:

(i) It was perhaps the most intense cyclone ever to cross the Queensland coast, a central pressure of 27 inches of mercury (914 mb) being recorded.

(ii) It destroyed a pearling fleet with the loss of over 300 lives.

(iv) A storm surge of over 40 ft height accompanied the landfall of the cyclone. This may well be an Australian record.
"Some aboriginals from a camp near Cape Melville were assisting shipwrecked men out of the water. A change of wind or a sudden gust swept round the hills and blew the natives into the water. They struggled hard, but were unable to reach land again, and were driven out to sea and drowned."
Ensuring reliability/homogeneity

- 1872-2010 (after settlement of Cairns)
- Category 3, 4 and 5 TCs pooled
- Attention restricted to TCs making land-falls over most densely populated part of coast—from Cairns in QLD to Ballina in NSW 1600km to the south.
Basic Statistics

- Landfalls occurred during Dec-April only
- 81% during Jan-March
- 3.1 TCs per decade

ENSO impacts

- 2.3 per decade in “El Niño” years
- 4.2 per decade in “La Niña” years
- Multiple TCs only occurred in La Niña years
Number of severe TC land-falls
10y running averages

nTCs

1880 1900 1920 1940 1960 1980 2000
SPI_13yra, -SOI_13yra, IPO, -nTCs; all standardized & normalized; $r(SPI, SOI) = -0.85$, $r(SPI, IPO) = 0.88$, $r(SOI, IPO) = -0.79$, $r(nTCs, SOI) = 0.79$
Number of severe TC land-falls with and without SOI-related variability

\[ y = -0.0214x + 44.672 \]
\[ R^2 = 0.2023 \]

\[ y = -0.014x + 27.273 \]
\[ R^2 = 0.1251 \]
Summary

- A new homogeneous TC time-series for eastern Australia - longest for Southern Hemisphere
- 3.1 TCs/decade, ENSO modulates landfalls, multiple landfalls in La Niña years only
- Decadal variability in land-falls over eastern Australia strongly tied to decadal variability in the SPCZ, ENSO and the IPO
- Downward trend in landfalls, partly due to weakening of the Walker circulation

Reference: Callaghan and Power, 2010: Variability and decline in tropical cyclones making land-fall over eastern Australia since the late 19th century. *Climate Dynamics*. 
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SOI used extensively to estimate and predict changes linked to ENSO and changes in the Walker circulation (rainfall, streamflow, disease, tropical cyclones, …)

Correlation coefficient between SOI and equatorial MSLP pressure gradient (ΔP) = 0.83

ΔP = BoxE(5°S-5°N, 200°E-280°E) - BoxW(5°S–5°N, 80°E–160°E)

El Niño, weaker Walker circulation, SOI < 0
ENSO event frequencies and the SOI

Power & Kociuba 2010; cf. Vecchi et al. and IPCC AR4
The Walker circulation weakens in response to global warming (Vecchi et al. 2006; Meehl et al. 2007 (IPCC AR5); Power and Kociuba 2010)

“This obviously means that the SOI also declines in response to global warming”

“So part of observed decline in SOI due to global warming”
Or is it?
The Walker circulation weakens in response to global warming

The SOI does not decline in response to global warming.

The large observed decline in SOI is therefore natural.

Power & Kociuba, Climate Dynamics (submitted), 2010
We can therefore infer that:

- Observed weakening of Walker circulation over 20\textsuperscript{th} century due to both natural variability and external forcing

Supports conclusions of Meehl et al. 2009
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“The relationship between ENSO and Australian climate in both the model and the observations is strong in some decades, but weak in others. A series of decadal-long perturbation experiments are used to show that if these interdecadal changes are predictable, then the level of predictability is low”.
Suppose \( E_{LF} \) is a low pass filtered ENSO index, e.g.:

\[
E_{LF} = \sum_{k=0}^{m} \frac{\alpha}{m+1} E_{t-k}. \quad \text{and} \quad \textbf{r}(E, \text{SST}) = \alpha.
\]

Then

\[
\textbf{r}(E_{LF}, \text{SST}_{LF}) = \frac{<E_{LF}, \text{SST}_{LF}>}{\sqrt{[<E_{LF}, E_{LF}> <\text{SST}_{LF}, \text{SST}_{LF}>]}}. \tag{1}
\]

Now

\[
<E_{LF}, E_{LF}> = <E_t, E_t + E_{t+1} + E_{t+2} + \ldots + E_{t+m}> / (m+1)^2
+ <E_{t-1}, E_t + E_{t+1} + E_{t+2} + \ldots + E_{t+m}> / (m+1)^2
+ \ldots + <E_{t-m}, E_t + E_{t+1} + E_{t+2} + \ldots + E_{t+m}> / (m+1)^2
= (m+1)/(m+1)^2 = 1 / (m+1), \tag{2}
\]

where we have used the fact that \( E \) is white noise. Similarly

\[
<SST_{LF}, SST_{LF}> = 1/(m+1), \quad \text{so} \quad \tag{3}
\]

\[
<SST_{LF}, E_{LF}> = <SST_t, E_t + E_{t+1} + E_{t+2} + \ldots + E_{t+m}> / (m+1)^2
+ <SST_{t-1}, E_t + E_{t+1} + E_{t+2} + \ldots + E_{t+m}> / (m+1)^2
+ \ldots + <SST_{t-m}, E_t + E_{t+1} + E_{t+2} + \ldots + E_{t+m}> / (m+1)^2
= (m+1) <SST_t, E_t> / (m+1)^2
= \alpha / (m+1). \tag{4}
\]

Using (2)-(4) in (1) then gives

\[
\textbf{r}(E_{LF}, \text{SST}_{LF}) = \alpha.
\]
Decadal pattern much broader

=> Different physics in off-equatorial “wings”
\[ \frac{dT}{dt} = -aT + bE + cN \]

Fig. 17 Cross-correlation coefficients between NINO3 and the equatorial SST index defined in Fig.16, using raw (seasonal, grey curve) and low pass filtered output (using an 8 year running mean, black curve).

Power and Colman, Climate Dynamics, 2006; see also Newman et al. 2007 for similar behaviour in PDO Index.
Discovery: Off-equatorial sub-surface variability is a low pass filtered version of ENSO variability.

Discovery: Sub-surface ENSO-driven off-equatorial decadal variability is highly predictable.

Low pass filtering due to dominance of low frequency oceanic Rossby waves in response to ENSO wind-stresses.

Power and Colman, Climate Dynamics, 2006.
Wind-stress forced shallow water model and simplified coupled models

First EOFs from Wind-forced Shallow Water Model

Forcing applied everywhere

Off-equatorial forcing only

McGregor et al. 2007; see also Wang et al. 2003, Part 1
Summary

- Predictability of decadal changes in ENSO teleconnections seems limited
- Random changes in ENSO activity from decade-to-decade will drive ENSO-like decadal patterns
- However, there are robust differences between ENSO and decadal ENSO-like patterns: off-equatorial “wings”
- In wings predictability is enhanced
  - off-equator SST behaves as an ENSO-modified red noise
  - variability in off-equatorial sub-surface ocean is decadal and highly predictable (through dynamical low pass filtering of ENSO wind-stresses)
- Multi-year equatorial variability driven by off-equatorial wind-stresses in SWM, HCM, ICM
The End – thank you for listening!

Scott Power

Bureau of Meteorology
ENSO-like decadal patterns of variability (IPO/PDO)
Decadal changes in ENSO impacts are very (very) large

<table>
<thead>
<tr>
<th>IPOI</th>
<th>Correlation Coefficient</th>
<th>IPOI &lt; -0.5</th>
<th>IPOI &gt; +0.5</th>
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</thead>
<tbody>
<tr>
<td>Rainfall</td>
<td>0.7</td>
<td>0.0</td>
<td></td>
</tr>
<tr>
<td>Murray River flow</td>
<td>0.4</td>
<td>0.1</td>
<td></td>
</tr>
<tr>
<td>Temperature</td>
<td>-0.8</td>
<td>0.1</td>
<td></td>
</tr>
<tr>
<td>Crop yield</td>
<td>0.7</td>
<td>0.1</td>
<td></td>
</tr>
</tbody>
</table>

Power, Casey, Colman, Folland & Mehta, 1999
Climate Dynamics
Basic Statistics

Relative Frequency of Land-falling TCs
Observations and a Poisson Distribution with mean=observed mean (3.1 land-falls/decade)

Consistent with Solow & Nicholls 1990; McDonnell & Holbrook 2004
A Great Cyclone.

Mackay and District Devastated.

Fifty-five Inches of Rain in 83 Hours.

Destruction of Raw Sugar Stocks and Sugar Mills.

Damage Estimated at £1,000,000.
seriously south polar storm, with a low temperature.

A RECORD BAROMETER.

Mr. P. E. Armatti took the following aneroid readings during the height of the cyclone:—Sunday, 20th: 9 p.m., 29.5; 10 p.m., 29.4; 11 p.m., 29.3. Monday, 21st: 1 a.m., 29.7; 2 a.m., 28.6; 3 a.m., 28.5; 4 a.m., 28.4. (Barograph at Post Office at this time, 27.9.) 7.30 a.m., 28.0; 8.30 a.m., 28.3; 9 a.m., 28.5; 11 a.m., 29.0; 12 noon, 29.2. (Note the remarkable rise between 10 a.m. and 11 a.m.)

RECORD RAINFALLS.

The following is a list of heavy rains recorded in Queensland: Barcinda, February 1, 1913, 20.51in.; Buderim Mountain, January 11, 1898, 26.20; Cairns, April 2, 1911, 20.16; Harvey Creek, January 3, 16, which settled in future political relations Central Powers and M. Trotsky (Russ. Monday’s meeting, German-Russian company of Kuhlmann’s demand territorial negotiations exclusively on the political Government. that his Government differing from it, a mania had resorted Russian territory again to the burial. forms us at East as those Miss were buri-

or, senr., ldy found probably