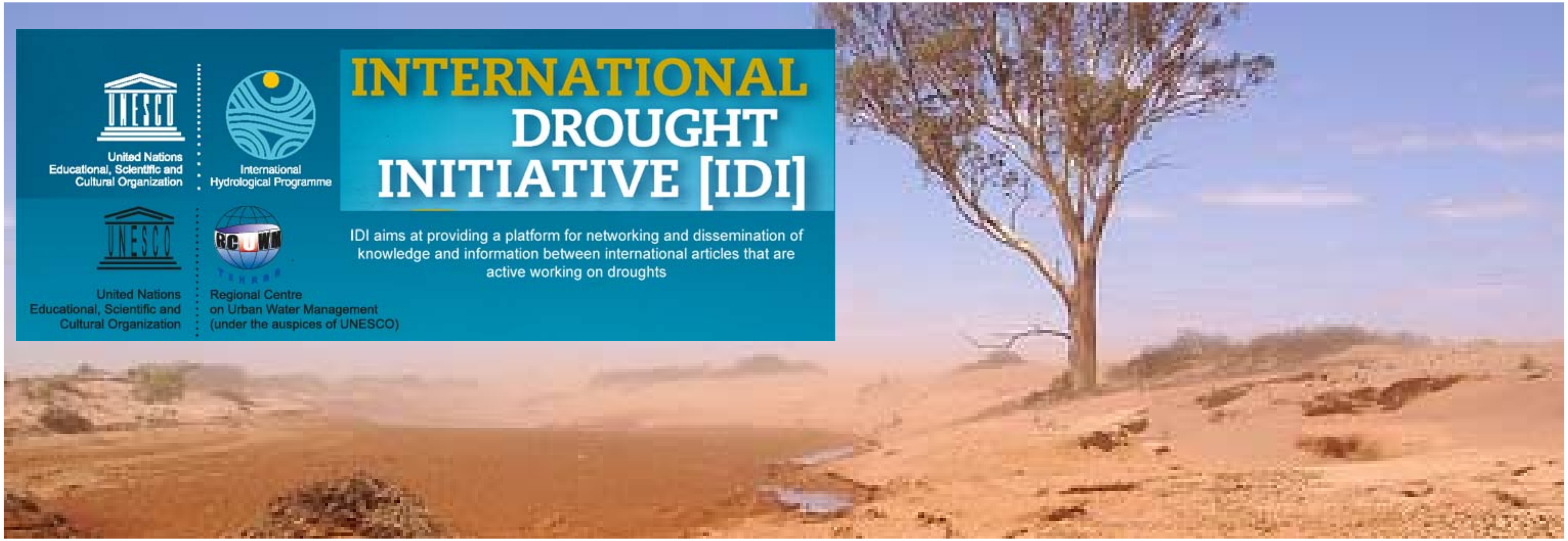

Supplementing instrumental records with palaeoclimate data to improve understanding and management of drought

THE UNIVERSITY OF NEWCASTLE AUSTRALIA

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(with acknowledgements to students and collaborators)

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- Commonly understood in many fields that “if you can’t measure it you can’t manage it”

- Extension of that is “if you want successful adaptation you need to understand the range of plausible impacts you are adapting to”

What is the problem?

- What if what we think is “rare” is common?
- What if what we think is “extreme” actually isn’t that extreme?
- What if planning for the worst flood/drought on record is not enough?

What is the problem?

- Infrastructure, planning, settlements, water policy etc are traditionally (and mostly still are) designed based on the "stationary climate assumption"
  - The chance of an extreme event occurring now and into the future is the same as it has been in the past
    - And by past we mean instrumental record (~50-100 yrs)
  - Also known in engineering as the **IID assumption** (extreme events are **I**ndependent and **I**dentically **D**istributed)

- What are the problems with this "stationary climate" or IID assumption?

What is wrong with the "stationary climate" or IID assumption?

- Instrumental record may not be long (or complete) enough to capture full range of historic variability
  - So worst "on record" may not be the worst that has occurred

- Instrumental record tells you nothing about the future (ok if future is same as the past but this appears unlikely - no century has ever been climatically the same as the previous plus there is also anthropogenic climate change)
  - So worst "on record" may not be the worst that is possible

What is wrong with the "stationary climate" or IID assumption?

- Climatological mechanisms that actually deliver climate extremes have not been taken into account (e.g. ENSO, IPO, IOD, SAM etc)
- Research focused on instrumental record (since ~1900, so ~100 years at best) has highlighted interannual to multidecadal epochs of enhanced/reduced flood, drought, bushfire risk across Australia (and globally as well)
- Anecdotal evidence supports the idea of 'changes in climate' occurring during the mid 1940's and again in the mid-1970's over eastern Australia
  - Clustering of floods in the 1950s, 1970s
  - > 10 years of below average rain with Federation Drought (1895-1902), WWII Drought (1937-1945), Millennium Drought (Big Dry) (1997-2010)

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Risk of extremes not stationary or IID but related to interannual and multidecadal ocean-atmospheric cycles

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Major drivers of Australian hydroclimatic variability

- Regional scale synoptic patterns
- Large-scale ocean-atmosphere processes (e.g. ENSO, IOD, SAM)

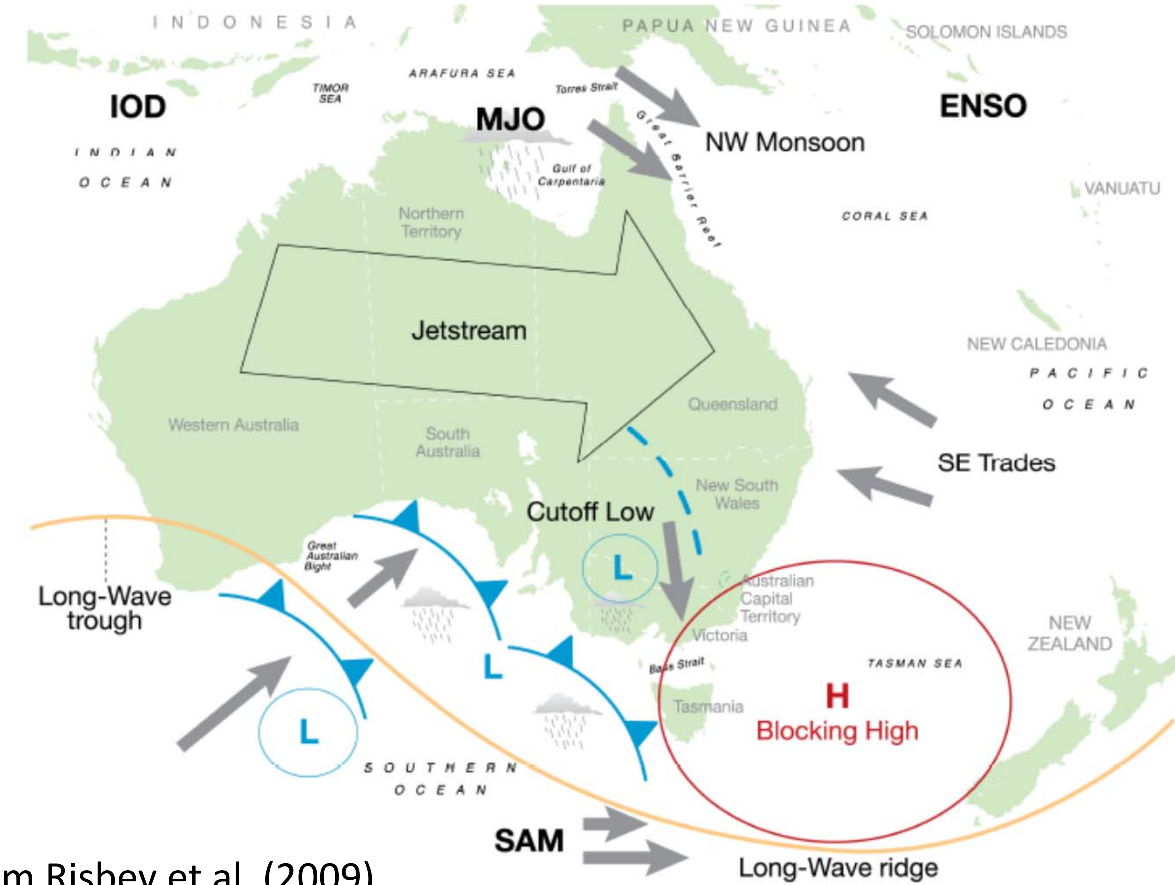

Figure from Risbey et al. (2009)

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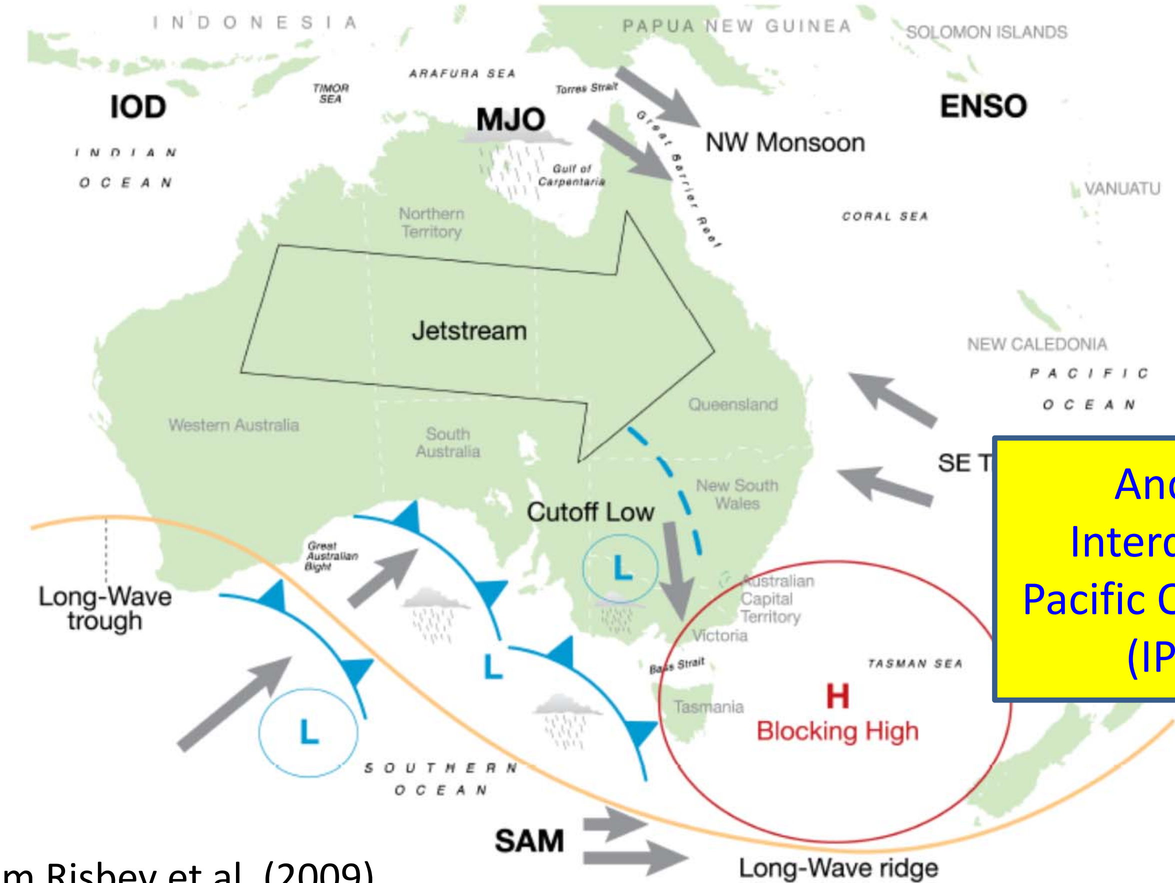
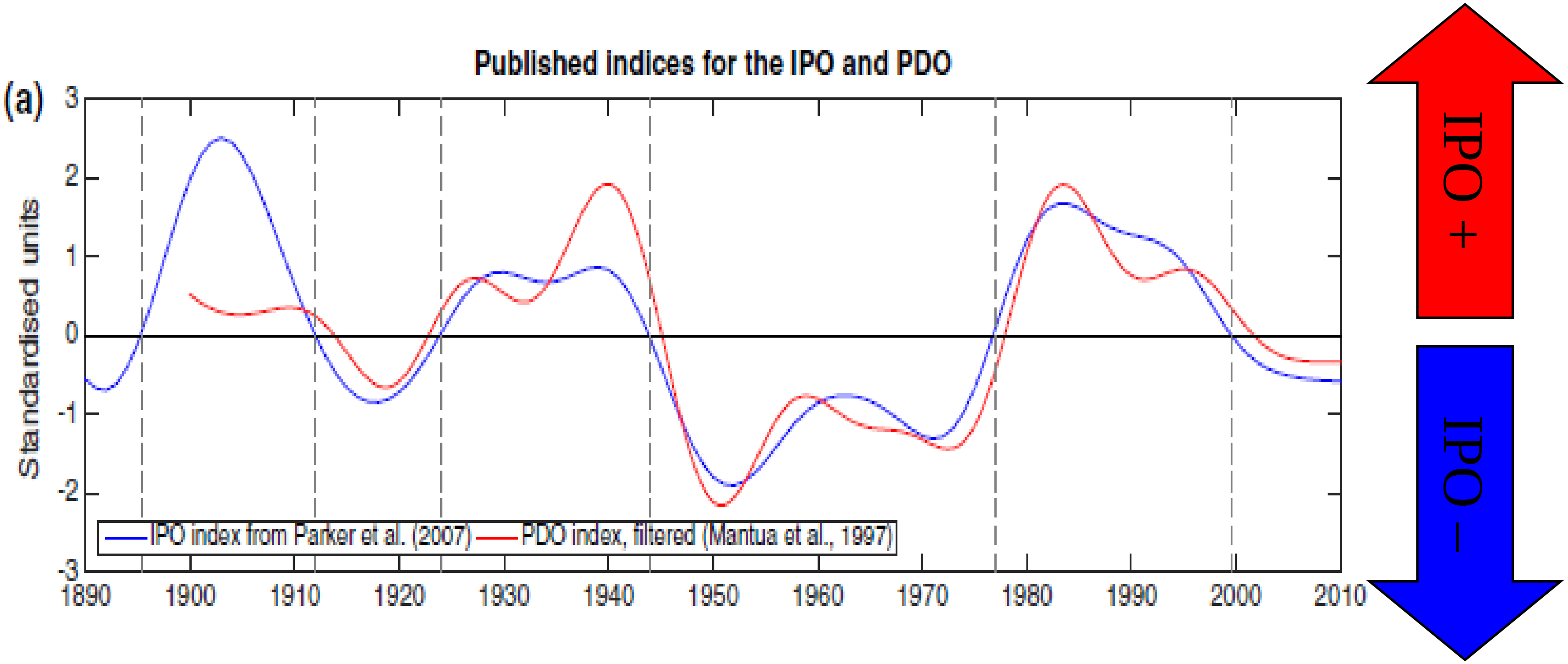


And the Interdecadal Pacific Oscillation (IPO)…

Figure from Risbey et al. (2009)

Interdecadal Pacific Oscillation (IPO)



- IPO associated with different magnitude and frequency of ENSO impacts for eastern Australia
  - IPO –ve => wetter La Niña and more of them =>wet epochs
  - IPO +ve => drier La Niña and less of them =>dry epochs

Thanks to UK Met Office for IPO index

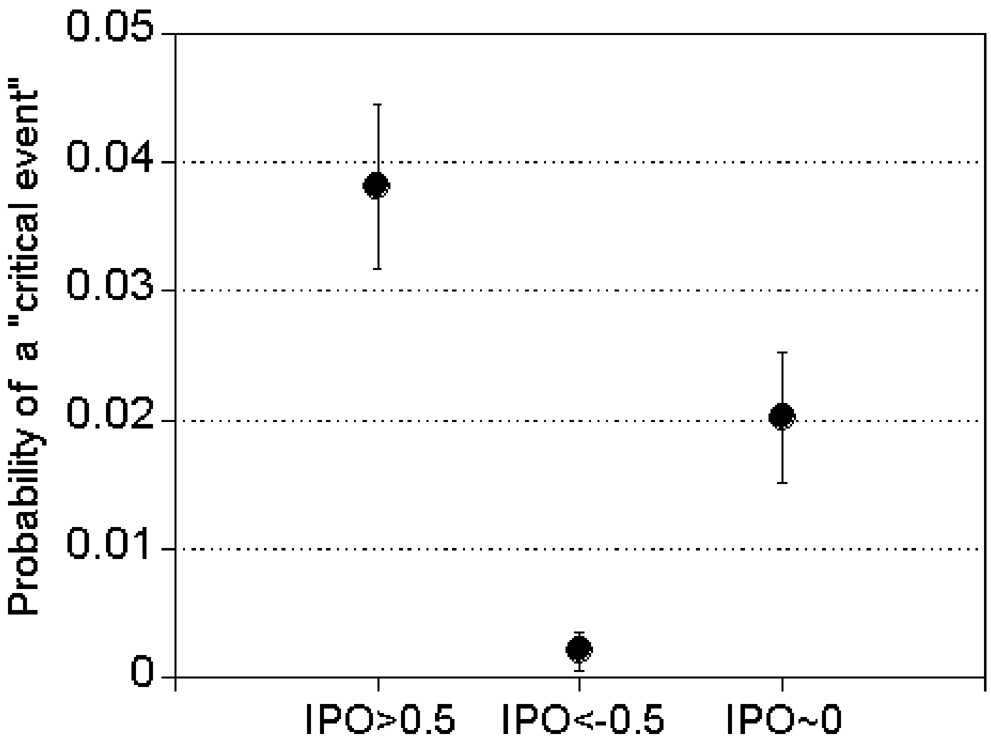
Estimating baseline climate risk

- Traditionally use empirical methods to estimate risk of climate related extremes
  - flood, drought, fire etc
- For example:
  - Get longest record possible from instrumental rainfall/evap observations)
  - Assume risk every year is the same (stationary climate or IID assumption)
  - Use Monte Carlo and Bayesian stats (e.g. FLIKE by George Kuczera) to quantify uncertainty
    - Stochastically generate 1000s of replicates with same underlying stats as “history”

But the stationary climate assumption is flawed…

….and there is strong evidence within the instrumental record of interannual to multidecadal epochs of enhanced/reduced flood, drought, bushfire risk

Multidecadal variability of drought risk – Newcastle case study



Kiem & Franks (2004): Multidecadal variability of drought risk. *Hydrol. Processes*.

- Grahamstown Reservoir: major water supply for Newcastle region, 6th largest residential region in Aust.
- Probability of a "critical event" (i.e. <30% storage) at Grahamstown Reservoir under current management practices
- Risk of falling below the critical level when IPO +ve ~20 times higher than it is during IPO -ve
- **Reason: "drier" La Niña and less of them when IPO +ve therefore reduced chance of recharge/refill**

Summary…

- Australasia's hydroclimate varies
- Hydroclimatic risk is non-stationary and is related to large-scale ocean-atmospheric processes (e.g. ENSO, IPO etc)

- **But is variability seen over the 50-100 year period where we have measured data representative of the true range of variability?**
- **Where does the last 50-100 years (i.e. the period on which all water infrastructure, planning and policy is based) fit in the context of pre-instrumental history?**

Supplementing instrumental records with palaeoclimate data to improve understanding and management of drought

Example based on ice core information

AGU PUBLICATIONS

Geophysical Research Letters

RESEARCH LETTER

10.1002/2014GL062447

Key Points:

- One kiloyear Interdecadal Pacific Oscillation and Australian drought record
- Twelfth century was exceptionally arid in eastern Australia
- Australian water policy needs to account for future megadroughts

Supporting Information:

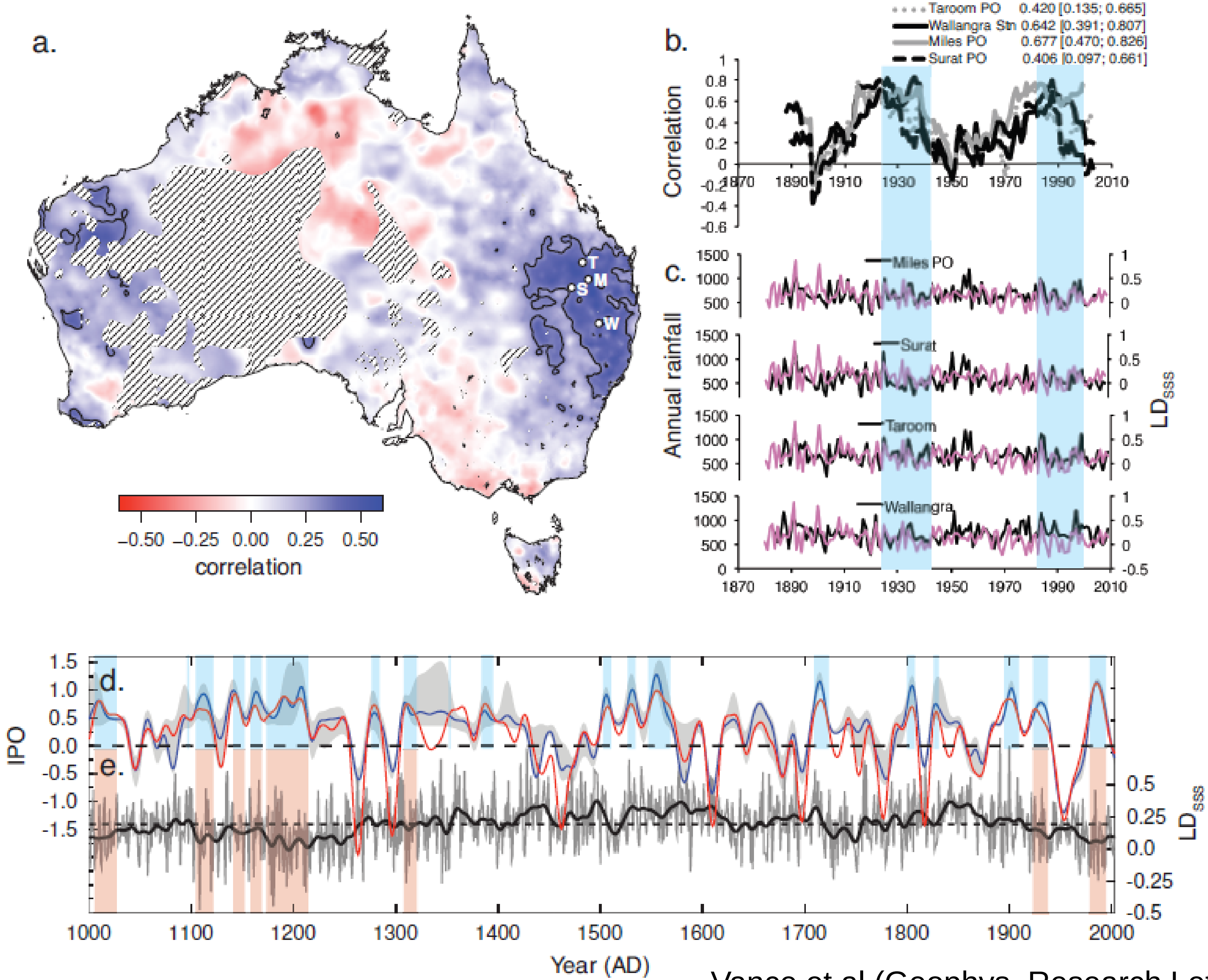
Interdecadal Pacific variability and eastern Australian megadroughts over the last millennium

T. R. Vance[1], J. L. Roberts[1,2], C. T. Plummer[3], A. S. Kiem[4], and T. D. van Ommen[1,2]

[1]Antarctic Climate and Ecosystems Cooperative Research Centre, University of Tasmania, Hobart, Australia, [2]Department of the Environment, Australian Antarctic Division, Hobart, Australia, [3]Institute for Marine and Antarctic Studies, University of Tasmania, Hobart, Australia, [4]Faculty of Science and Information Technology, University of Newcastle, Callaghan, Australia

Abstract The Interdecadal Pacific Oscillation (IPO) influences multidecadal drought risk across the Pacific, but there are no millennial-length, high-resolution IPO reconstructions for quantifying long-term drought risk. In Australia, drought risk increases in positive phases of the IPO, yet few suitable rainfall proxies and

- Ice cores from Antarctica (Vance et al 2015)
  - Changes to sea salt in ice cores at Law Dome is linked to changes in wind circulation patterns in the Indian and Pacific Oceans which is linked to changes in ENSO/IPO which is linked to rain/hydrology in eastern Australia
  - Use these links to reconstruct 1000y ENSO/IPO/east Aust rainfall



Vance et al (Geophys. Research Lett., Jan 2015)

What do pre-instrumental records tell us?

- Ice cores from Antarctica (Vance et al GRL 2015):
  - "mega-droughts" (>5 year duration)
    - Six mega-droughts occur between AD 1000-1320 including a 39 year drought (AD 1174-1212)
    - 1100-1212 had drought conditions > 80% of the time
  - **Droughts similar to, and longer than, `Big Dry' (1997-2008), WWII (1935-1945) and Federation (late 1890s) droughts have occurred on a regular basis in Australia's past (last 1000 yrs)**

Hydrol. Earth Syst. Sci., 20, 1–15, 2016
www.hydrol-earth-syst-sci.net/20/1/2016/
doi:10.5194/hess-20-1-2016

Hydrology and Earth System Sciences
Open Access
EGU

An ice-core-derived 1013-year catchment-scale annual rainfall reconstruction in subtropical eastern Australia

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[1]Antarctic Climate & Ecosystems Cooperative Research Centre, University of Tasmania, Hobart, Tasmania 7001, Australia
[2]Centre for Water, Climate and Land Use, University of Newcastle, Callaghan, NSW 2308, Australia
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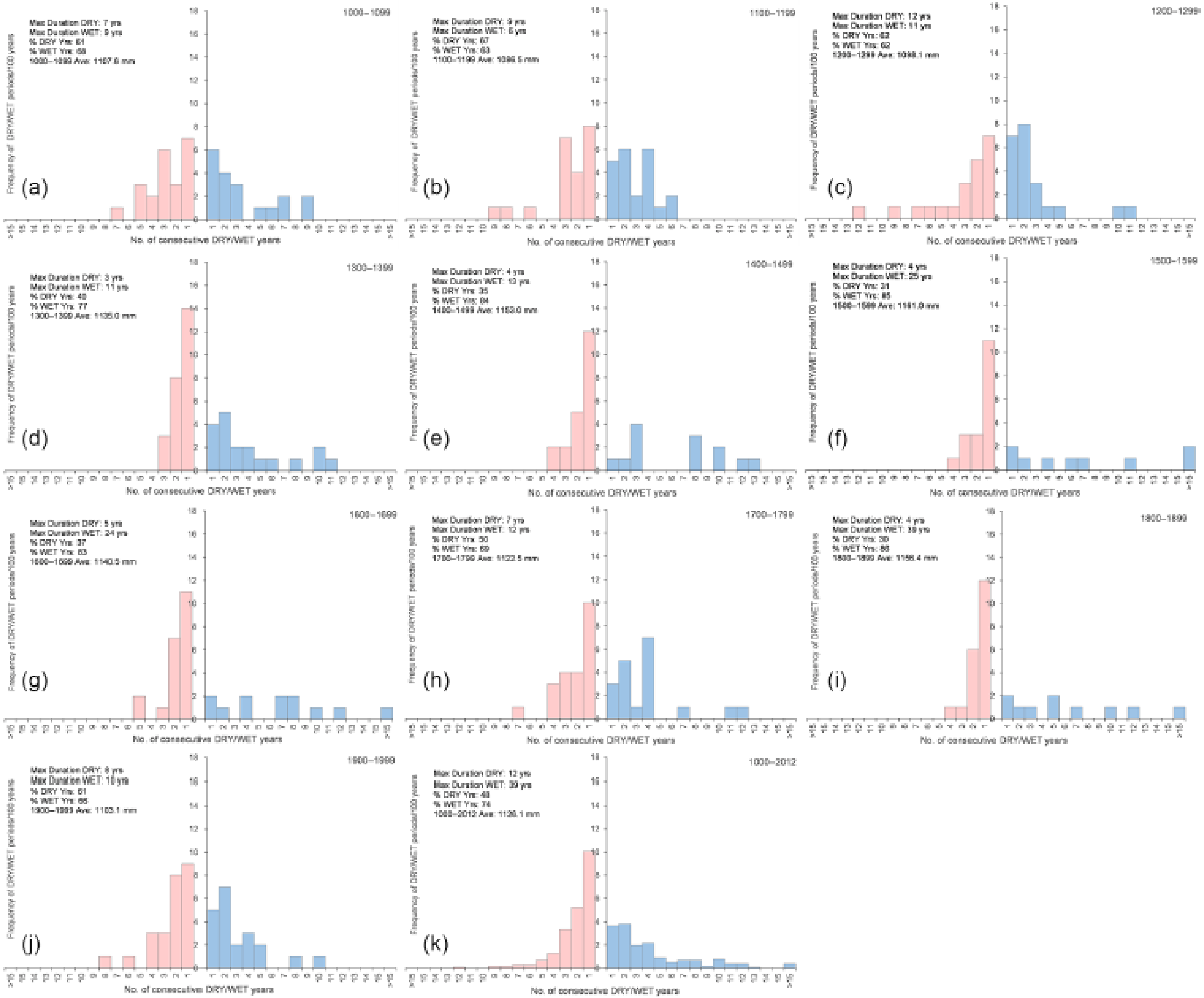
Received: 23 October 2015 – Published in Hydrol. Earth Syst. Sci. Discuss.: 3 December 2015
Revised: 24 March 2016 – Accepted: 11 April 2016 – Published:

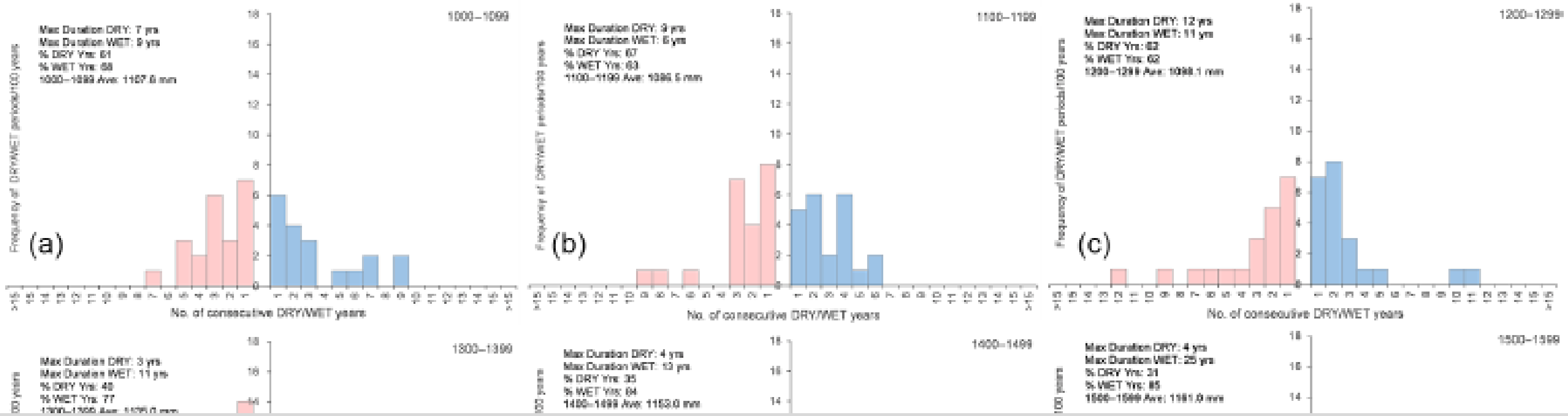
Abstract. Paleoclimate research indicates that the Australian instrumental climate record (~ 100 years) does not cover the full range of hydroclimatic variability that is possible. To better understand the implications of this on catchment-scale water resources management, a 1013-year (1000–2012 common era (CE)) annual rainfall reconstruction was produced for the Williams River catchment in coastal eastern Australia. No high-resolution paleoclimate proxies are located in the region and so a teleconnection between summer sea salt deposition recorded in ice cores from East Antarctica and rainfall variability in eastern Australia was exploited to

1 Introduction

Water and catchment management systems (e.g., drought and flood mitigation strategies) and water resources infrastructure have traditionally been designed based on the trends, patterns and statistics revealed in relatively short instrumental climate records (i.e., for Australia usually less than 100 years of data recorded post-1900) (Verdon-Kidd and Kiem, 2010; Ho et al., 2014; Cosgrove and Loucks, 2015; Razavi et al., 2015). This is a concern as Australian paleo-



(a)
1000–1099
Max Duration DRY: 7 yrs
Max Duration WET: 9 yrs
% DRY Yrs: 61
% WET Yrs: 68
1000–1099 Ave: 1107.6 mm
(b)
1100–1199
Max Duration DRY: 9 yrs
Max Duration WET: 6 yrs
% DRY Yrs: 67
% WET Yrs: 63
1100–1199 Ave: 1086.5 mm
(c)
1200–1299
Max Duration DRY: 12 yrs
Max Duration WET: 11 yrs
% DRY Yrs: 62
% WET Yrs: 62
1200–1299 Ave: 1098.1 mm
(d)
1300–1399
Max Duration DRY: 3 yrs
Max Duration WET: 11 yrs
% DRY Yrs: 40
% WET Yrs: 77
1300–1399 Ave: 1135.0 mm
(e)
1400–1499
Max Duration DRY: 4 yrs
Max Duration WET: 13 yrs
% DRY Yrs: 35
% WET Yrs: 84
1400–1499 Ave: 1153.0 mm
(f)
1500–1599
Max Duration DRY: 4 yrs
Max Duration WET: 25 yrs
% DRY Yrs: 31
% WET Yrs: 85
1500–1599 Ave: 1161.0 mm
(g)
1600–1699
Max Duration DRY: 5 yrs
Max Duration WET: 24 yrs
% DRY Yrs: 37
% WET Yrs: 83
1600–1699 Ave: 1140.5 mm
(h)
1700–1799
Max Duration DRY: 7 yrs
Max Duration WET: 12 yrs
% DRY Yrs: 50
% WET Yrs: 69
1700–1799 Ave: 1122.5 mm
(i)
1800–1899
Max Duration DRY: 4 yrs
Max Duration WET: 39 yrs
% DRY Yrs: 30
% WET Yrs: 88
1800–1899 Ave: 1166.4 mm
(j)
1900–1999
Max Duration DRY: 8 yrs
Max Duration WET: 10 yrs
% DRY Yrs: 61
% WET Yrs: 66
1900–1999 Ave: 1103.1 mm
(k)
1000–2012
Max Duration DRY: 12 yrs
Max Duration WET: 39 yrs
% DRY Yrs: 48
% WET Yrs: 74
1000–2012 Ave: 1126.1 mm
Frequency of DRY/WET periods/100 years
No. of consecutive DRY/WET years



Annual (Oct-Sept) mean (instrumental, 1900-2010) = 1100.0 mm
Annual (Oct-Sept) mean (reconstruction, 1000-2012) = 1126.1 mm

+2.4%

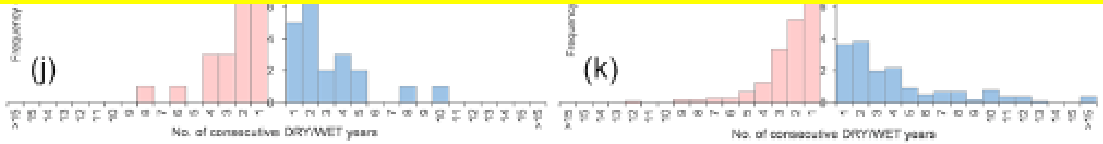
Annual (Oct-Sept) StDev (instrumental, 1900-2010) = 73.9 mm
Annual (Oct-Sept) StDev (reconstruction, 1000-2012) = 83.0 mm

+12.3%

Longest run of dry years (instrumental,1900-2010) = 8 years (1935-42)
Longest run of dry years (reconstruction,1000-2012) = 12 years (1193-1204)

Longest run of wet years (instrumental,1900-2010) = 10 years (1905-14)
Longest run of wet years (reconstruction,1000-2012) = 39 years (1830-1868)

Instrumental misrepresents mean, stdev, persistence, clustering, sequencing....



Ice core data : Hydrological risk management implications

Establishing a Risk Portfolio

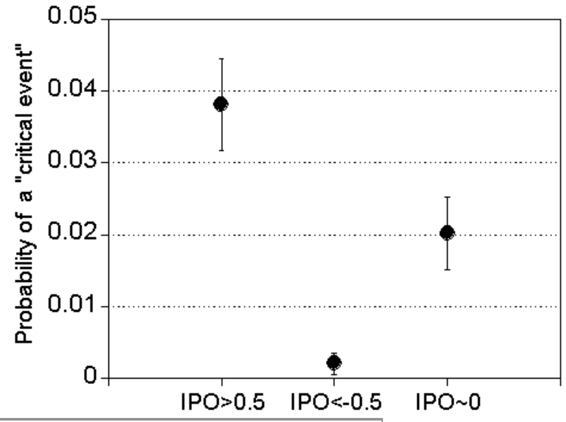
- **Aims of risk portfolio**
  - Customer impacts must reflect community expectations
  - Droughts must be manageable
- **Proposed criteria for the risk portfolio:**
  - Set a limit on the frequency and severity of restrictions
  - Set a limit on the risk of triggering drought contingency measures

HUNTER WATER

Restrictions:
=> Maximum frequency = 1 in 10 years
=> On average shall not impact > 5% of the time

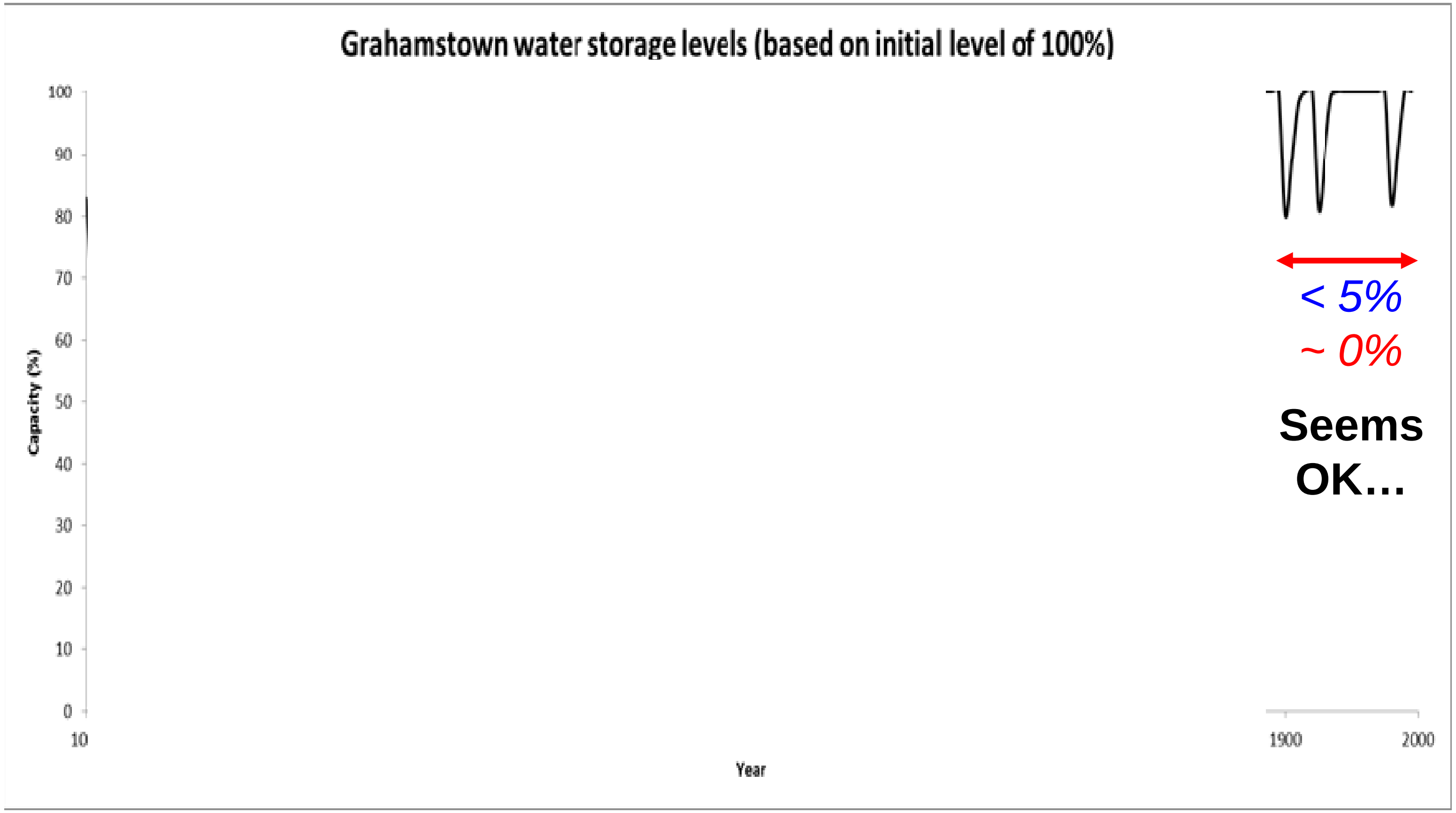
“Critical event” needs to be “unlikely”
Chance of running out of water needs to be “~zero”

Implications for water resource management: a case study of Grahamstown Dam

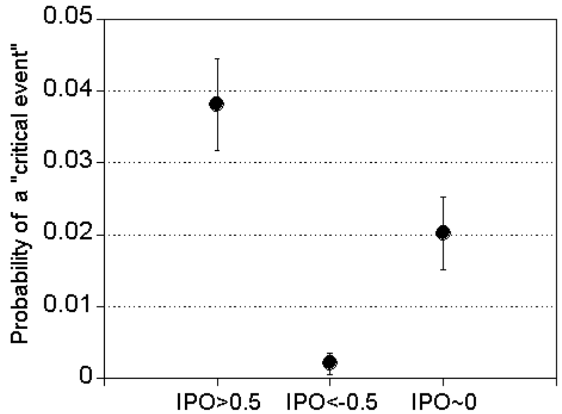


Probability of restrictions (start at 70% storage)

Probability of “critical event” (< 30% storage)



Implications for water resource management: a case study of Grahamstown Dam



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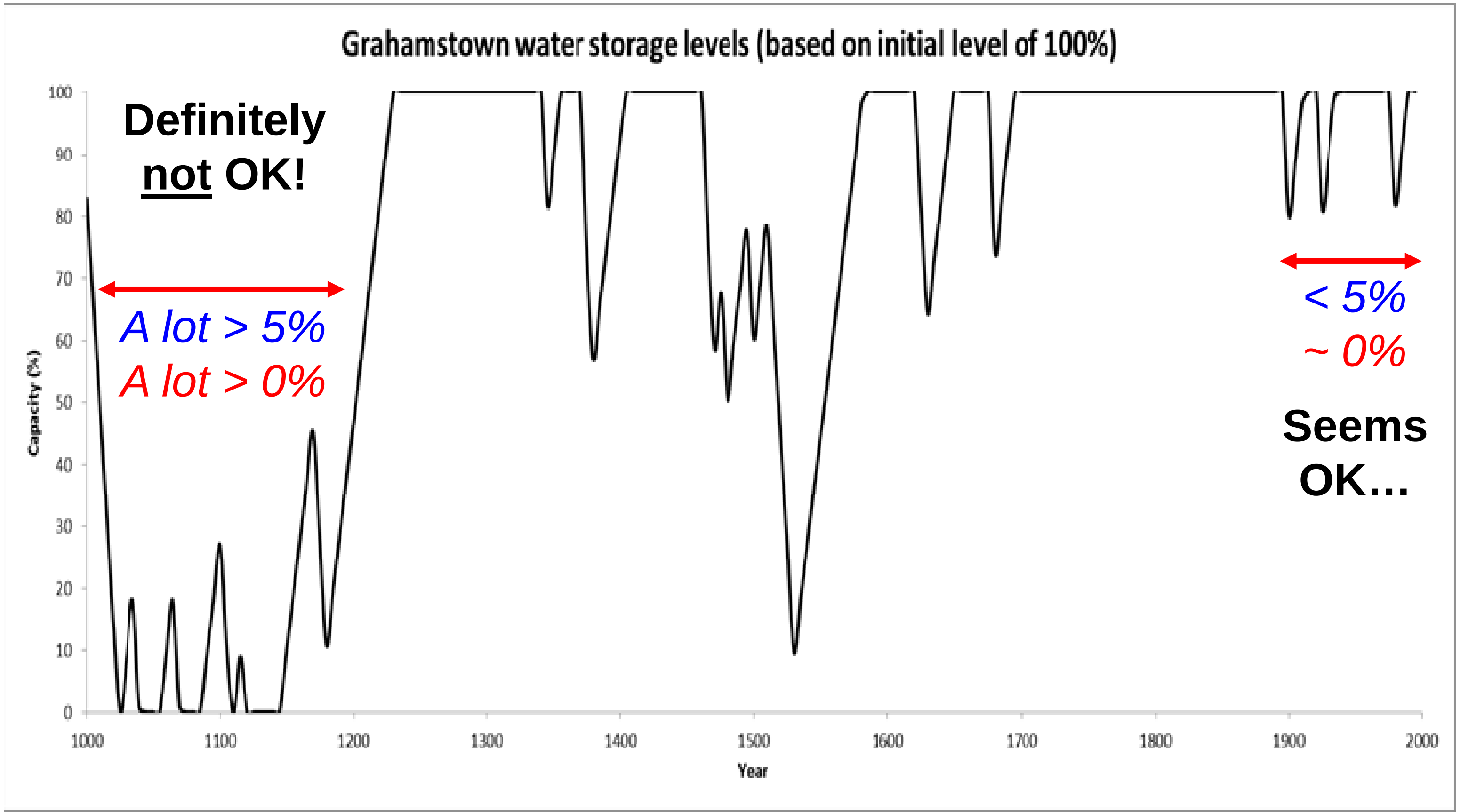
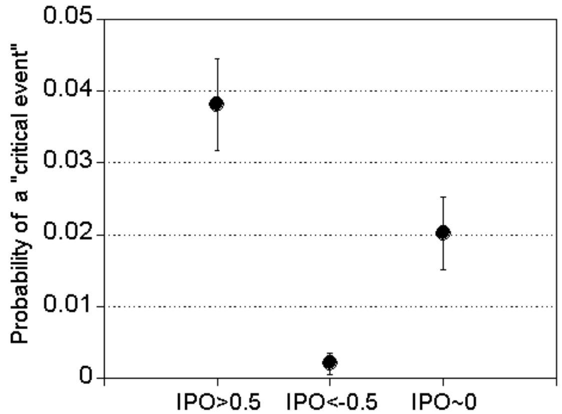


- **Limits exceeded for frequency and severity of restrictions**
- **Multiple triggers for expensive drought contingency plans (e.g. new dam, desal)**

Implications for water resource management: a case study of Grahamstown Dam



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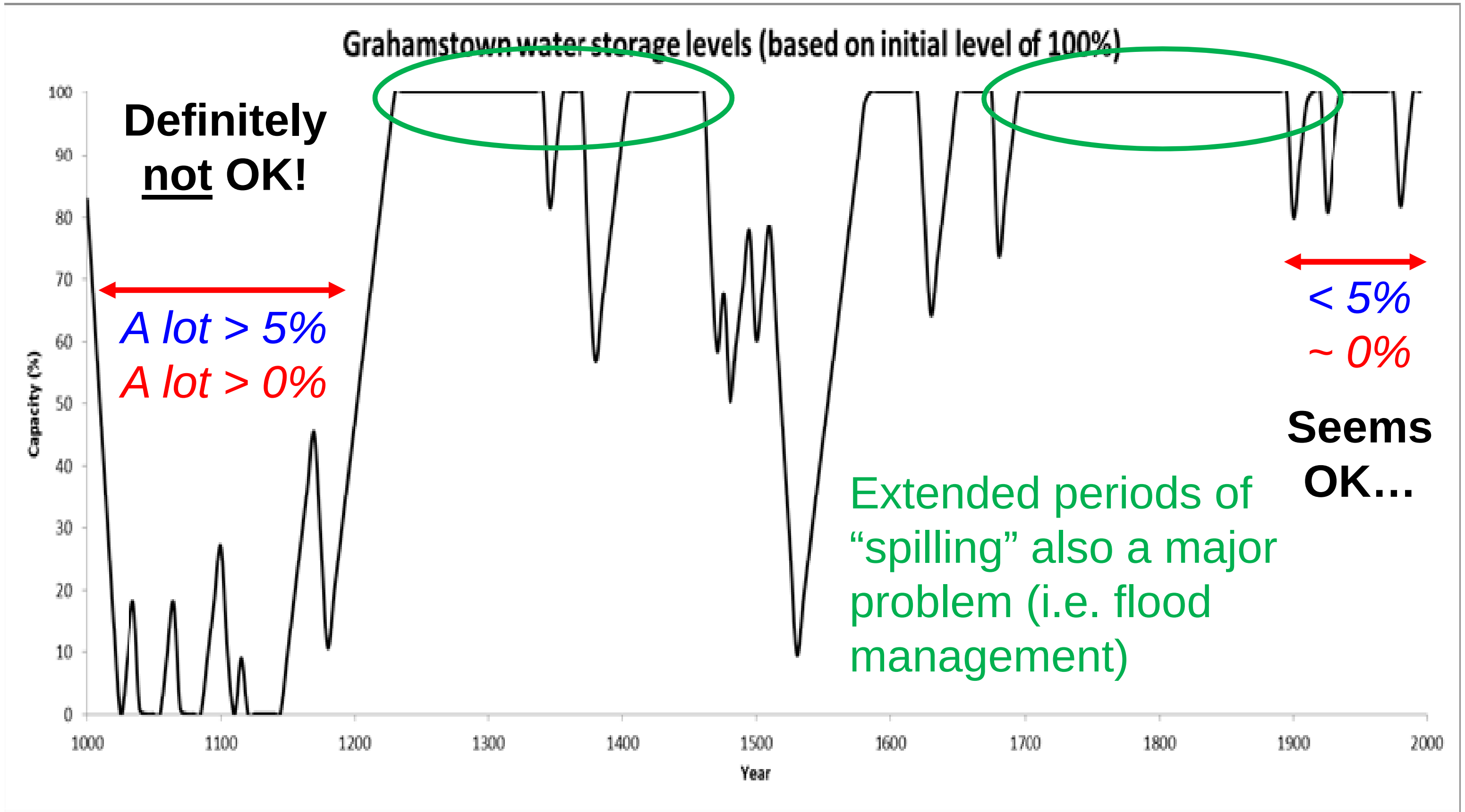

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CONCLUSIONS

Conclusions

- Droughts similar to, and longer than, `Big Dry‘ (1997-2008), WWII (1935-1945) and Federation (late 1890s) droughts **have occurred on a regular basis in Australia's past (last 1000 yrs)**
- Six mega-droughts (>5 yrs) occurred between AD 1000-1320 **including a 39 y drought (AD 1174-1212)**
- Wet epochs that are **longer (wetter?) than anything seen in the instrumental record** have occurred several times over the last 1000 years
  - ~1400-1450, 1500-1620, mid-1800s
  - Goodwin et al show increased ECL activity at these times also…..gives insights into the physical mechanisms

Conclusions

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Challenges the underlying assumptions governing water resources planning and management:

1) That droughts > 5 y are rare (~3 in 100 yrs)
2) That droughts > ~15 y are not possible
3) That flood/drought risk is stationary
4) That IFDs, ARIs, AEPs etc established based only on instrumental record are sufficient…