Critical review of climate change and water modelling in Queensland – overview of climate science

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Review of climate science

Review led by:
Anthony Kiem – University of Newcastle
Francis Chiew and Jai Vaze – CSIRO

Key input from:
Jozef Syktus – Department of Environment and Science
Chantal Donnelly – Bureau of Meteorology

What is the problem?

- Water models, infrastructure, planning, settlements 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 instrumental record
  - 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 only relevant for future if future climate is similar to that covered by observed record (palaeoclimate records and anthropogenic climate change suggests this is unlikely)
  - So worst "on record" may not be the worst that is possible
- Water models calibrated/validated on instrumental record may be unreliable if hydroclimatic conditions differ to what is in instrumental record

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 over the last ~15-20 years has highlighted interannual to multidecadal epochs of enhanced/reduced flood, drought, bushfire risk across Australia
- Anecdotal evidence also 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 (1895-1902), WWII (1937-1945) and Millennium (1997-2010) droughts

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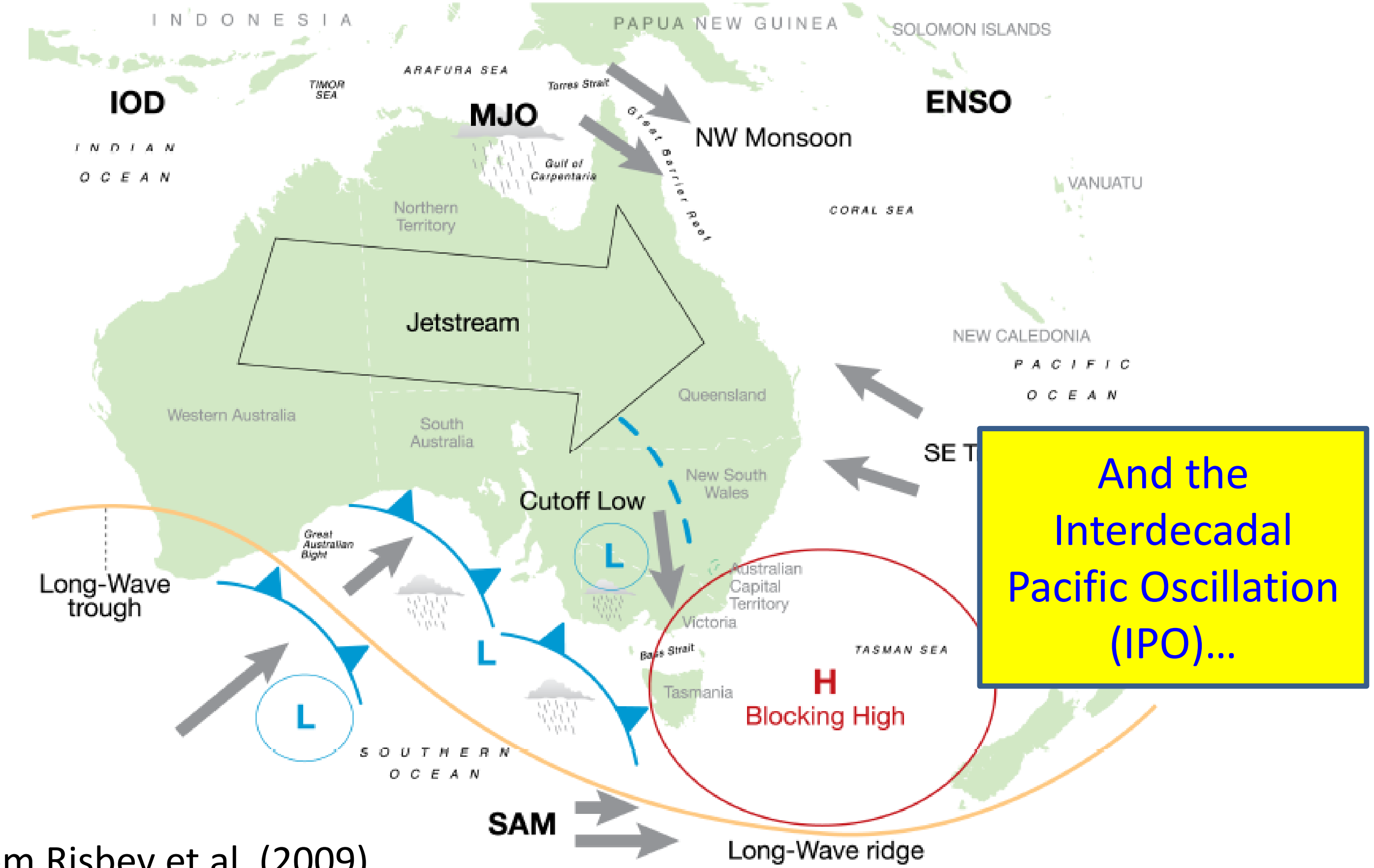
Risk of extremes not stationary or IID but related to interannual and multidecadal ocean-atmospheric cycles

CLIMATE VARIABILITY

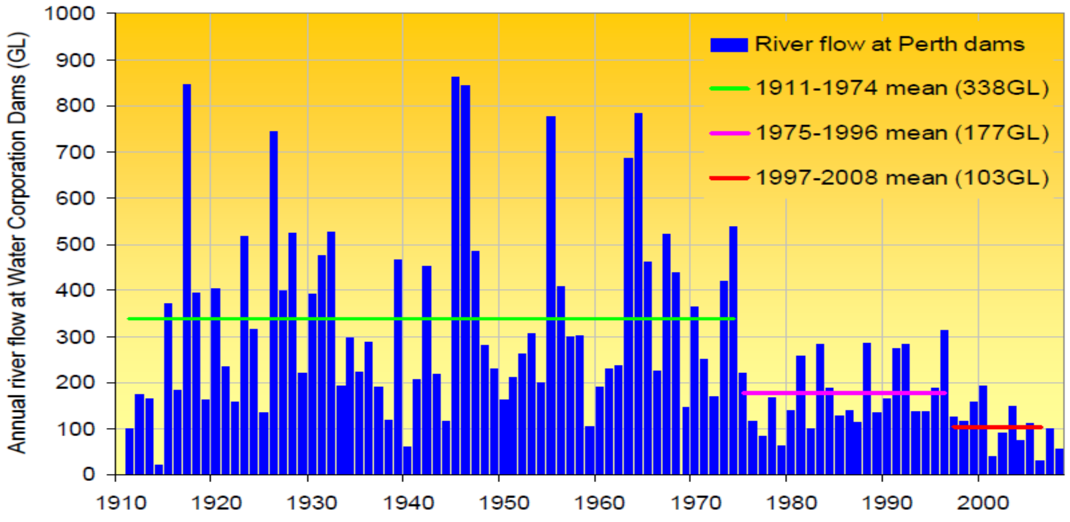
Major drivers of Australian hydroclimatic variability

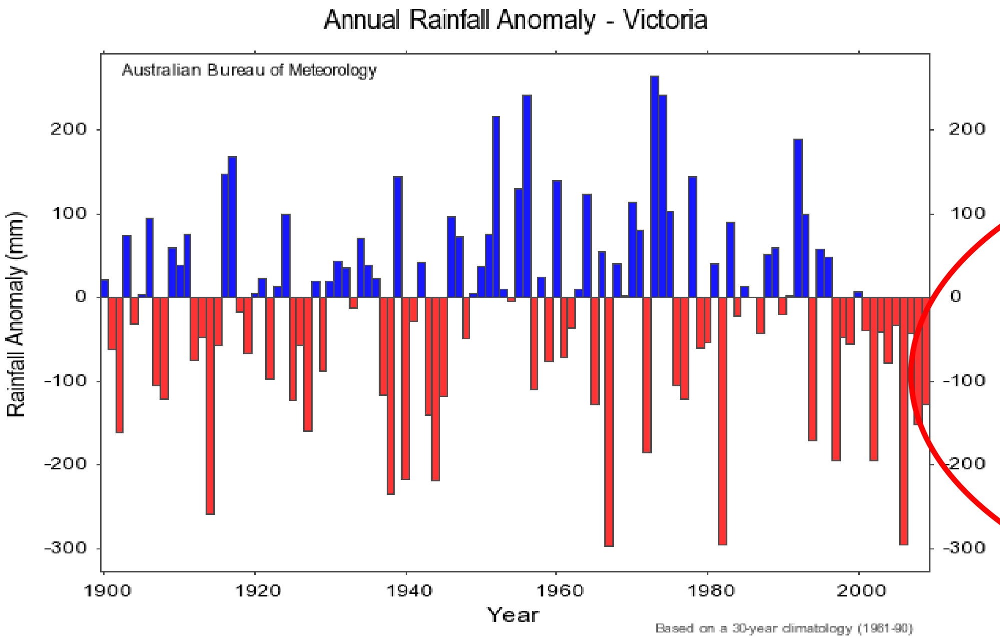
- Regional scale synoptic patterns
- Large-scale ocean-atmosphere processes (e.g. ENSO, IOD, SAM)



And the Interdecadal Pacific Oscillation (IPO)…

Figure from Risbey et al. (2009)





Stationarity assumption is flawed

- Climate is non-stationary
  - Multi-year epochs of wet/dry conditions do exist
- Impacts associated with anthropogenic climate change not considered
  - Future may not look like past
  - Frequency, location, magnitude, duration of extremes may change
- Physical climate mechanisms that actually deliver climate extremes have been ignored
  - Chance of extreme event is not the same from one year to next and is strongly related to large-scale climate drivers like ENSO

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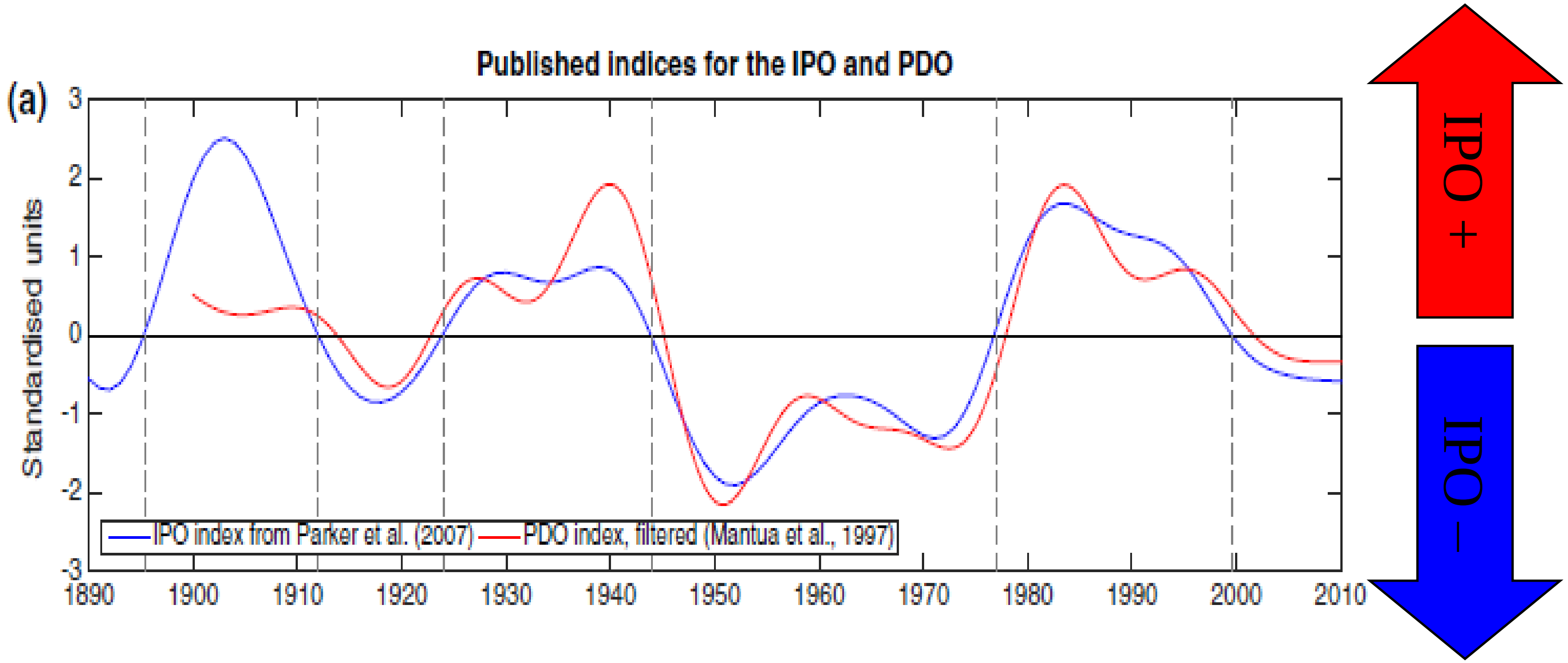
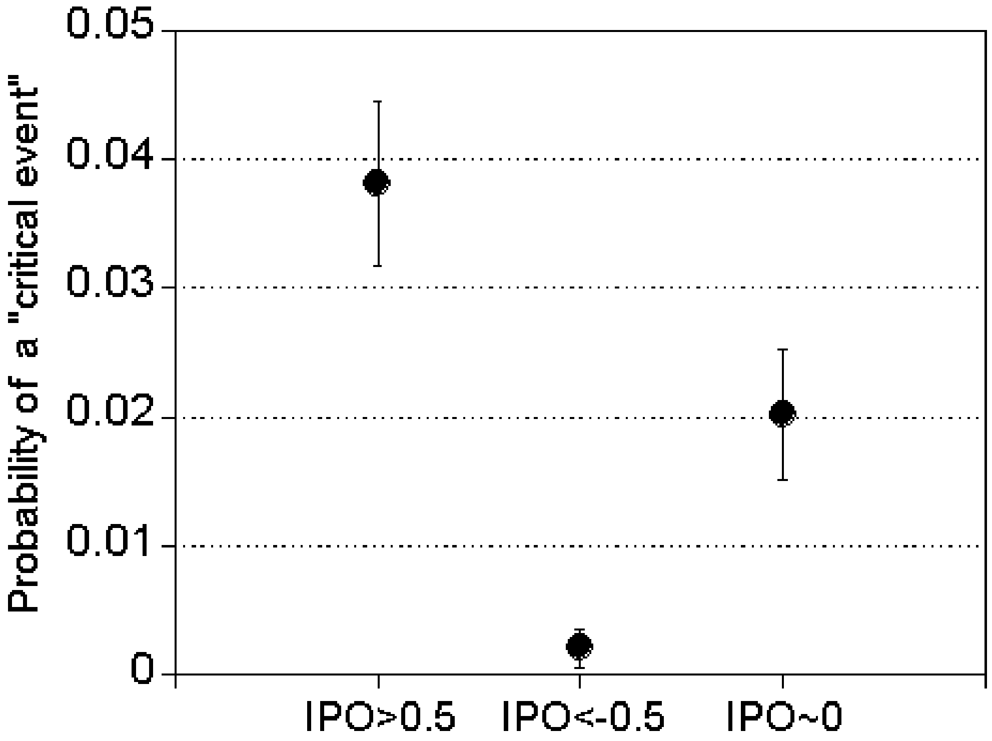
Wet/Dry epochs defined by Interdecadal Pacific Oscillation (IPO)



- 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

Newcastle case study – multidecadal variability of drought risk



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 management practices as they were in 2002
- 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**

What do pre-instrumental records tell us?

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:

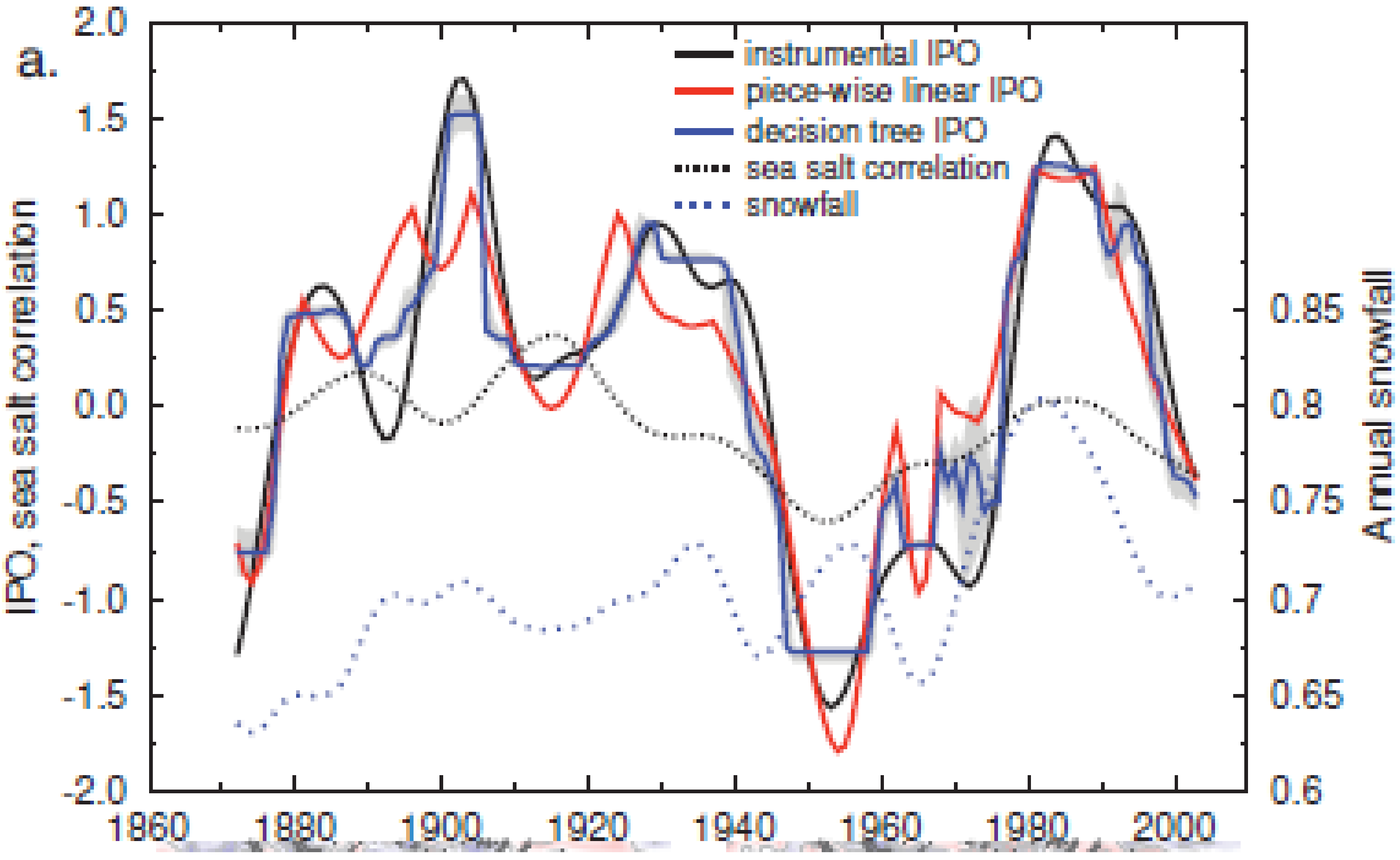
Interdecadal Pacific variability and eastern Australian megadroughts over the last millennium

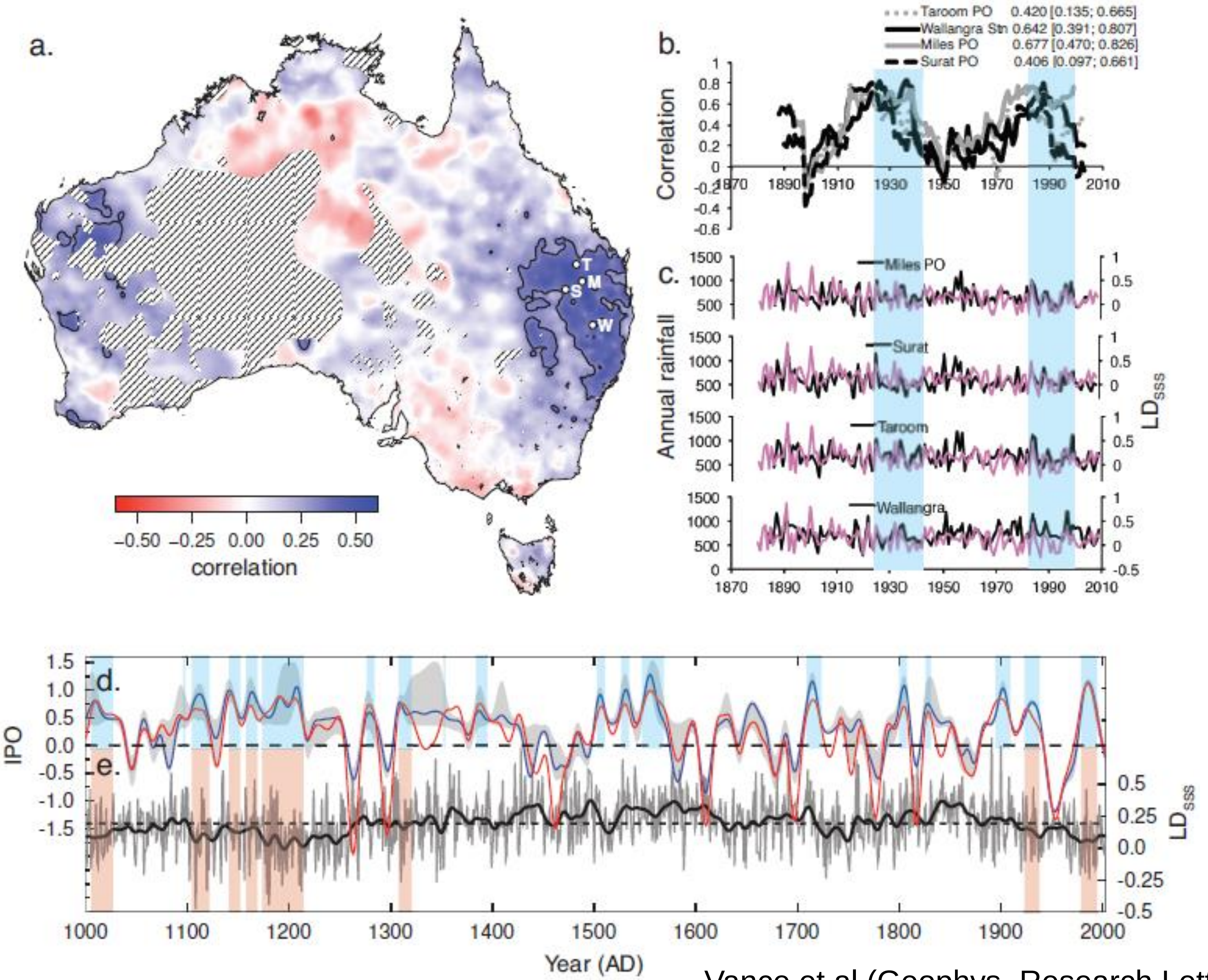
T. R. Vance[1], J. L. Roberts[1,2], C. T. Plummer[3], A. S. Kiem[4], and T. D. van Ommen[1,2]

[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 1000yr ENSO/IPO/east Aust rainfall


a.
instrumental IPO
piece-wise linear IPO
decision tree IPO
sea salt correlation
snowfall
IPO, sea salt correlation
Annual snowfall
2.0
1.5
1.0
0.5
0.0
-0.5
-1.0
-1.5
-2.0
0.85
0.8
0.75
0.7
0.65
0.6
1860
1880
1900
1920
1940
1960
1980
2000



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" (>10 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, Millennium (1997-2008), WWII (1935-1945) and Federation (late 1890s) droughts have occurred on a regular basis in Australia's past (last 1000 yrs)**

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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

Carly R. Tozer[1,2], Tessa R. Vance[1], Jason L. Roberts[3,1], Anthony S. Kiem[2], Mark A. J. Curran[3,1], and Andrew D. Moy[3,1]

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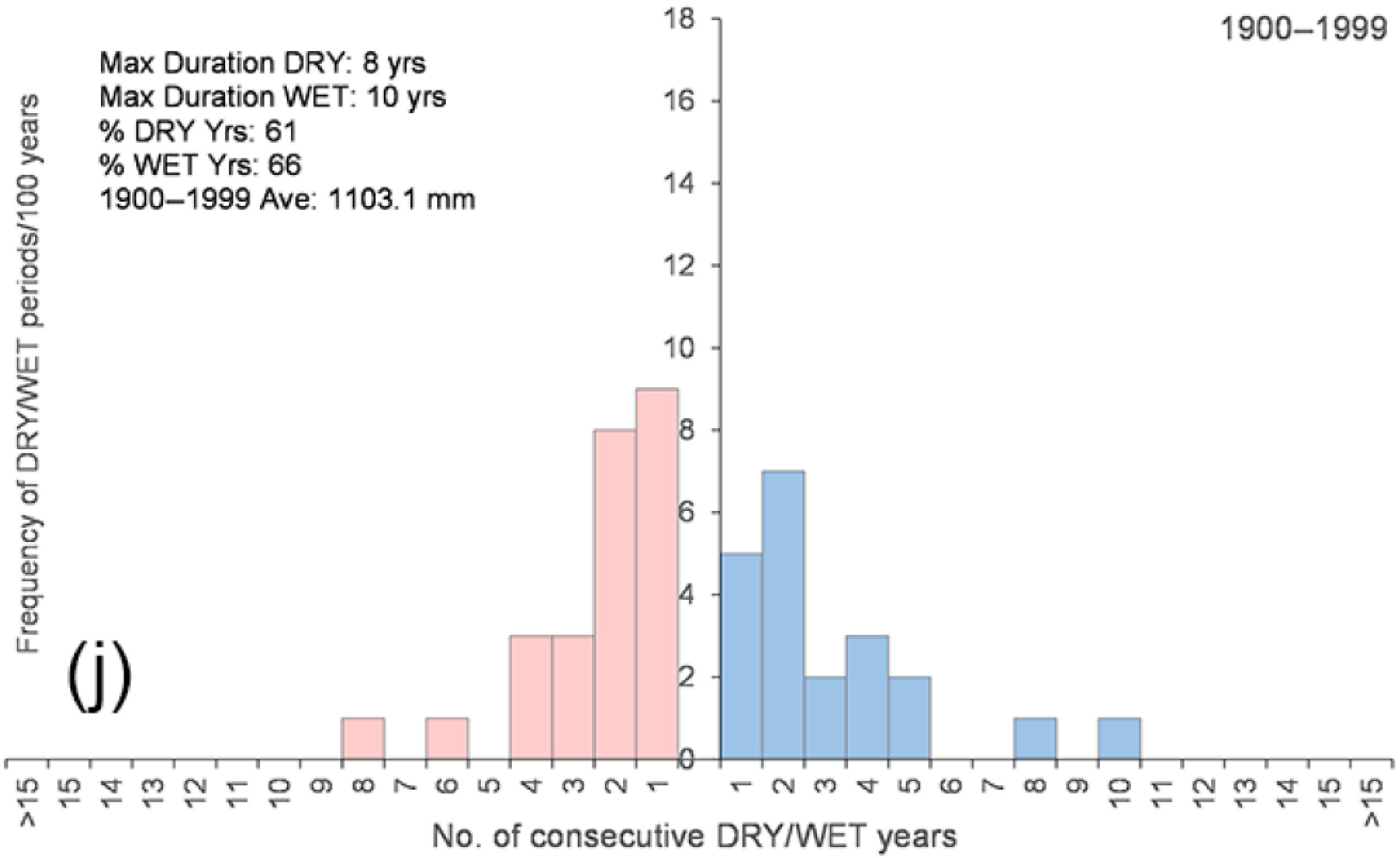
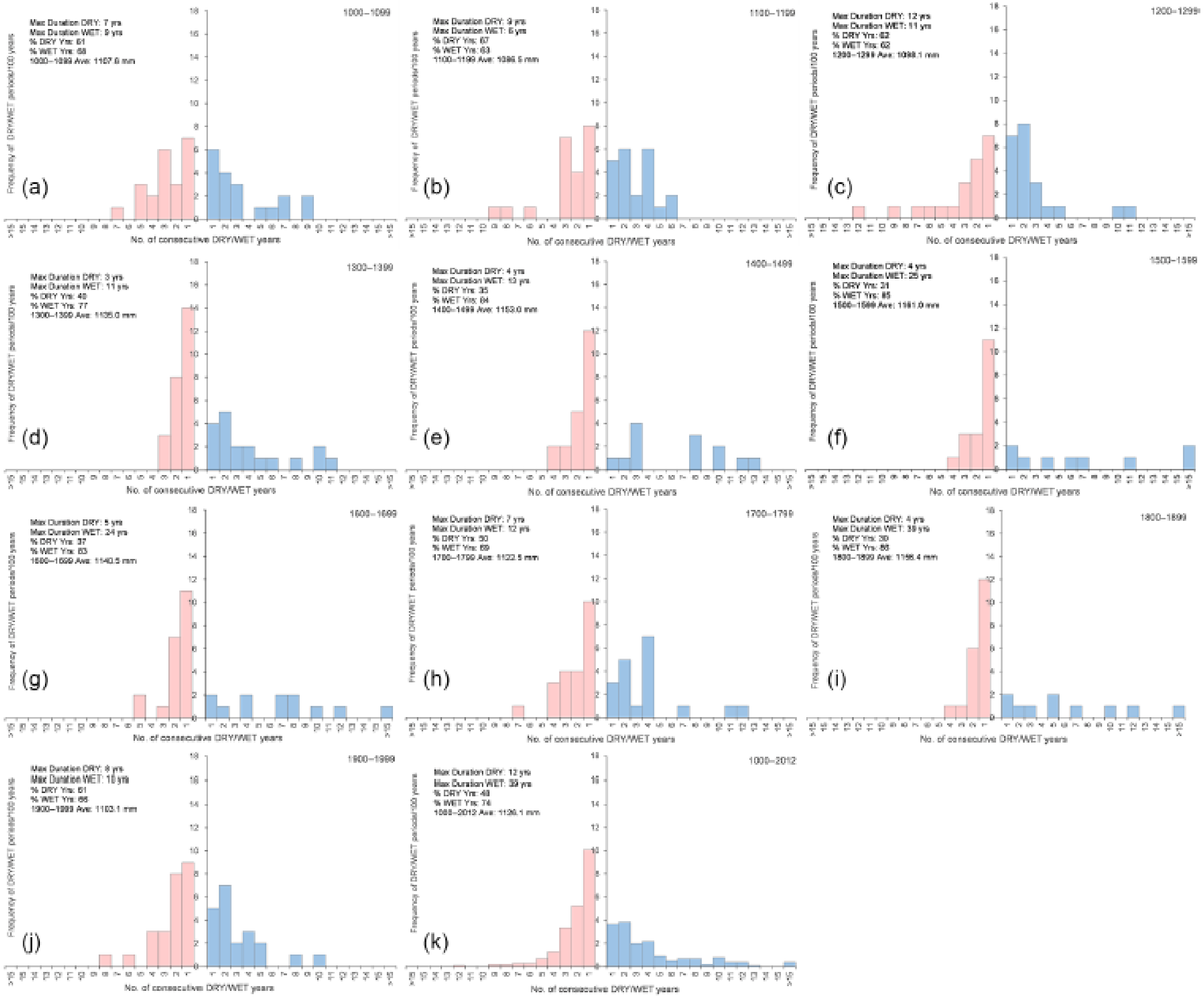
Received: 23 October 2015 – Published in Hydrol. Earth Syst. Sci. Discuss.: 3 December 2015
Revised: 24 March 2016 – Accepted: 11 April 2016 – Published:

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

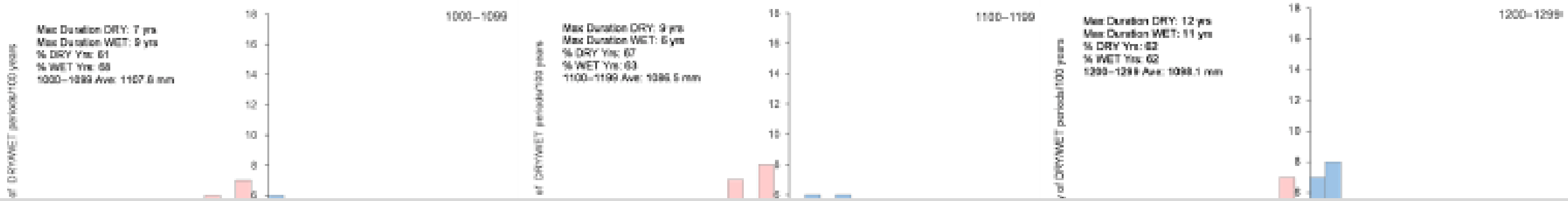
1 Introduction

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-


1900–1999
Max Duration DRY: 8 yrs
Max Duration WET: 10 yrs
% DRY Yrs: 61
% WET Yrs: 66
1900–1999 Ave: 1103.1 mm
(j)
Frequency of DRY/WET periods/100 years
No. of consecutive DRY/WET years
>15
15
14
13
12
11
10
9
8
7
6
5
4
3
2
1
0
2
4
6
8
10
12
14
16
18



(a)
1000–1099
Max Duration DRY: 7 yrs
Max Duration WET: 9 yrs
(b)
1100–1199
Max Duration DRY: 9 yrs
(c)
1200–1299
Max Duration DRY: 12 yrs
Max Duration WET: 11 yrs
(d)
1300–1399
Max Duration DRY: 3 yrs
Max Duration WET: 11 yrs
(e)
1400–1499
Max Duration DRY: 4 yrs
Max Duration WET: 13 yrs
(f)
1500–1599
Max Duration DRY: 4 yrs
Max Duration WET: 25 yrs
(g)
1600–1699
Max Duration DRY: 5 yrs
Max Duration WET: 24 yrs
(h)
1700–1799
Max Duration DRY: 7 yrs
Max Duration WET: 12 yrs
(i)
1800–1899
Max Duration DRY: 4 yrs
Max Duration WET: 39 yrs
(j)
1900–1999
Max Duration DRY: 8 yrs
Max Duration WET: 10 yrs
(k)
1000–2012
Max Duration DRY: 12 yrs
Max Duration WET: 39 yrs
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

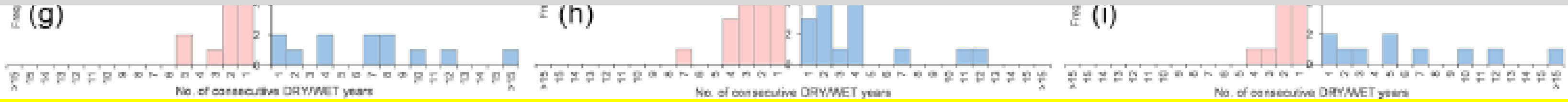
+2.4%

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....

~10 centuries…all very different….but stationarity assumption relies on ~1900-2010 being representative of full range of what has occurred in the past and what is possible in the future…….

But that’s just ice cores from Antarctica…

…and Antarctica is a long way away from eastern Australia…

…is it “real”?
…should we trust info from ice cores?

Hard to “verify” but we can look at what multiple, independent lines of evidence suggest….

Alternative Source of pre-instrumental info #1

What do pre-instrumental records tell us?

Tree rings from Tasmania…

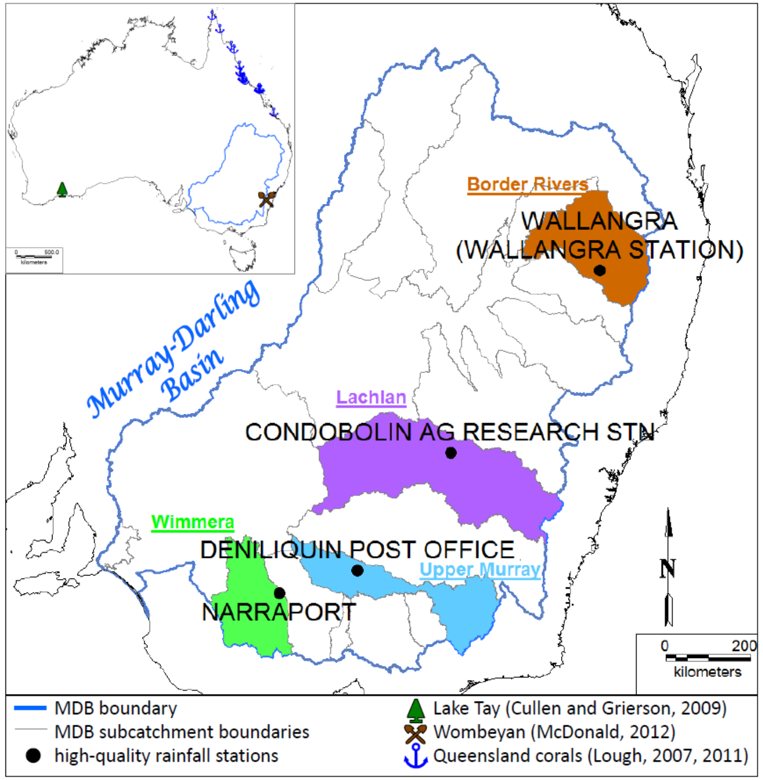
- See also the recent (~Dec 2015) papers by Kathy Allen et al….and their year ~500 yr Australia & NZ drought atlas (1500-2012)
  - Using tree rings from Tasmania (and corals also) to reconstruct streamflow for eastern Aust and NZ
  - *"….despite the severity of the Millennium Drought, the five worst single years of drought happened before 1900."*
  - http://iopscience.iop.org/article/10.1088/1748-9326/10/12/124002

Alternative Source of pre-instrumental info #2

What do pre-instrumental records tell us?

- Corals from Queensland (1661-present)
- Tree rings from WA (1655-present)
- Speleothems from Wombeyan (750BC-present)

Rainfall in four different sub-catchments of the Murray-Darling Basin reconstructed back ~2750 years

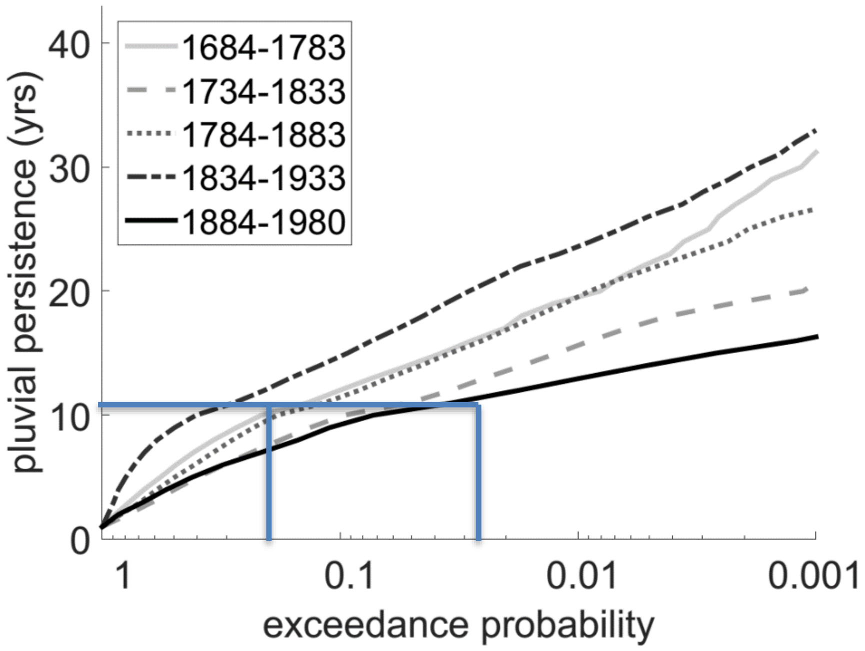


From Michelle Ho’s PhD (July 2014)

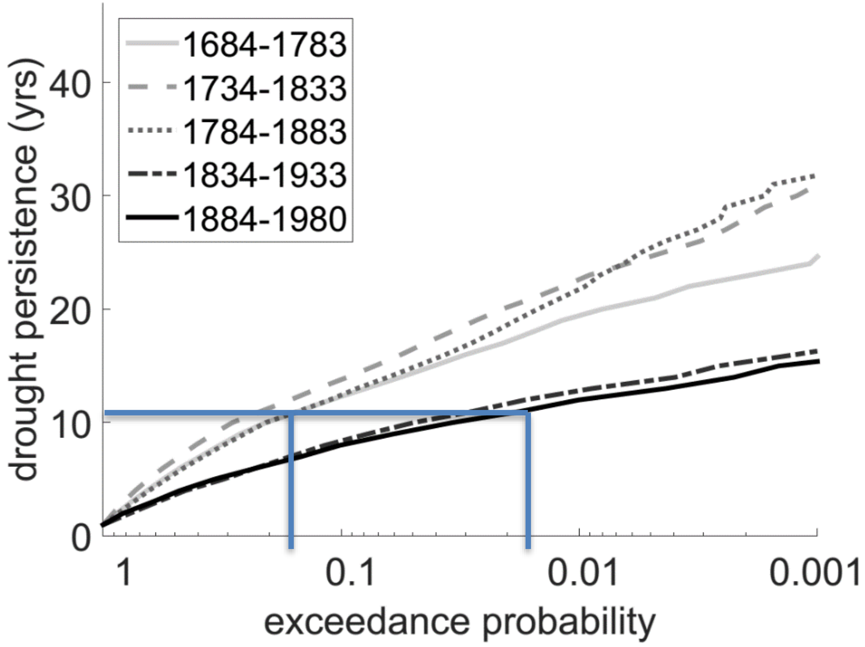
Alternative Source of pre-instrumental info #2

Exceedance Probability – risk from instrumental different to risk pre-instrumental

WET



DRY



Probability of both dry and wet periods exceeding a decade **at least 10 times more likely prior to 1883** than suggested by instrumental records.

From Michelle Ho's PhD (July 2014)

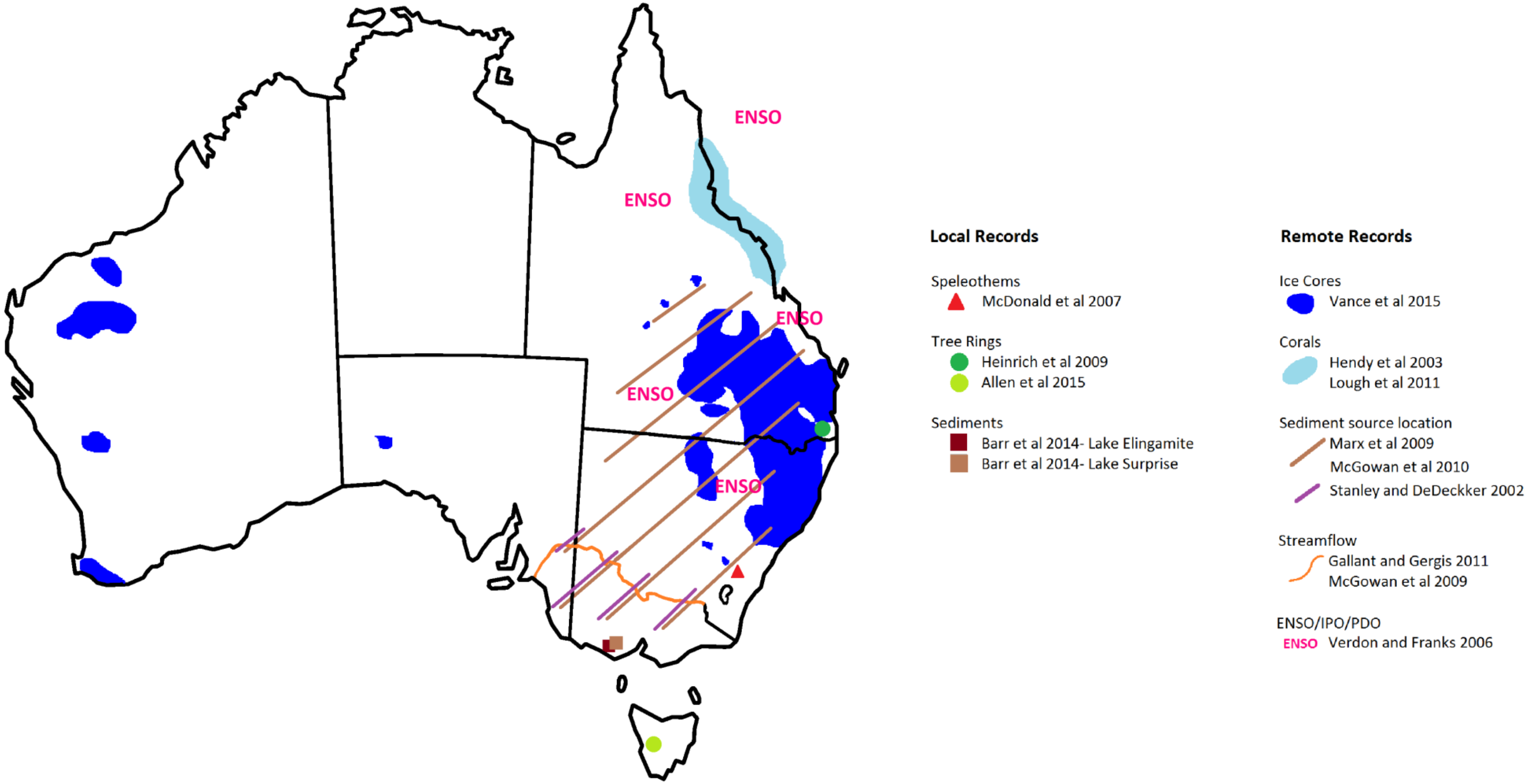
Alternative Source of pre-instrumental info #3

What do pre-instrumental records tell us?

- Recently completed work (Anna Flack and Kiem – 2015 Honours project at UON)

- Investigating **multiple** pre-instrumental hydroclimate records relevant to eastern Australia and what this means for water resource management
  - Rather than just focus on one (or a few) records try to use everything that is available to see if there is consensus....multi-proxy or composite approach (similar to using GCM ensemble)

Location map for existing (published) paleoclimate records



Alternative Source of pre-instrumental info #3

From Anna Flack's Honours (Nov 2015)

Create a wet/dry time series using a composite of paleoclimate records that are relevant to eastern Australia

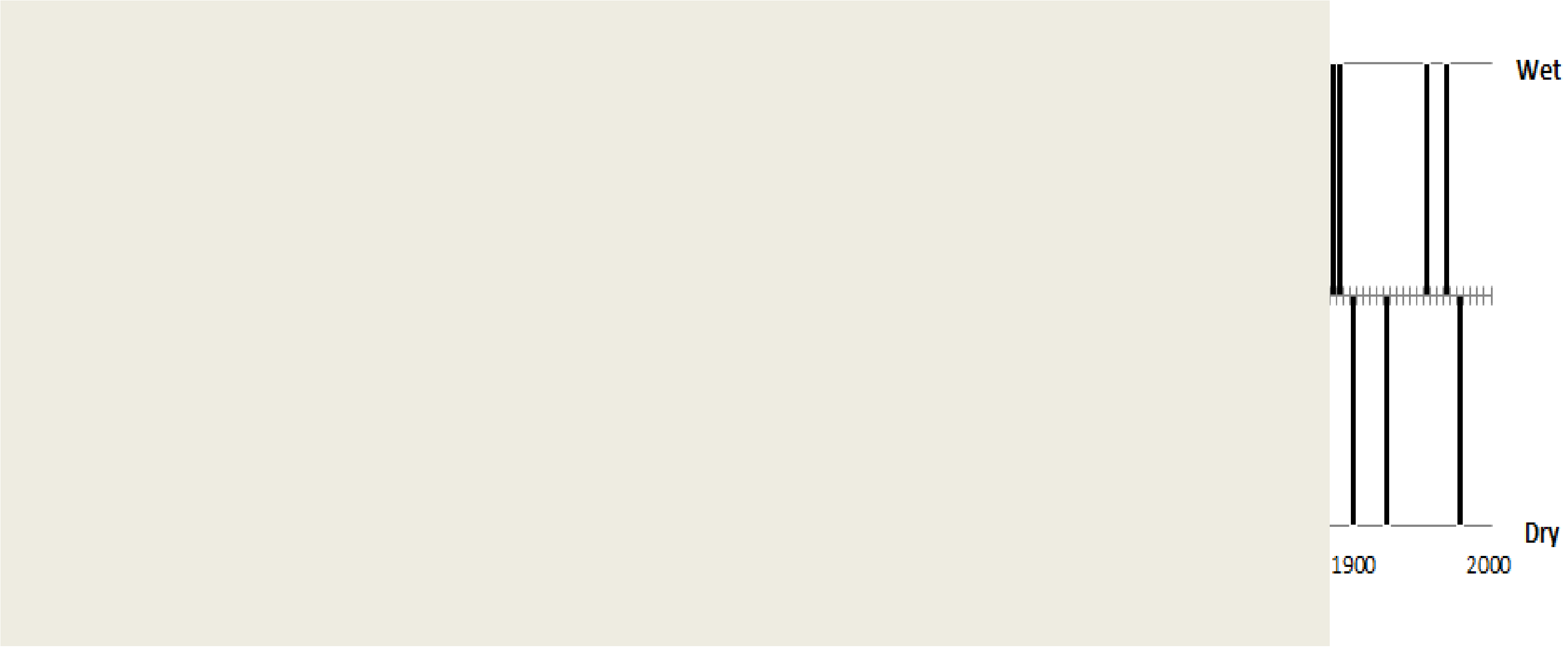
A 5-yearly temporal resolution was used to determine the:

- Occurrence of wet and dry epochs
- Frequency of wet and dry epochs
- Duration of wet and dry epochs
- Spatial extent of wet and dry epochs

Alternative Source of pre-instrumental info #3

Occurrence of wet and dry epochs

Composite index captures wettest/driest epochs observed in instrumental period
This gives some confidence that what is indicated pre-instrumental is realistic



Total records wet/dry composite index

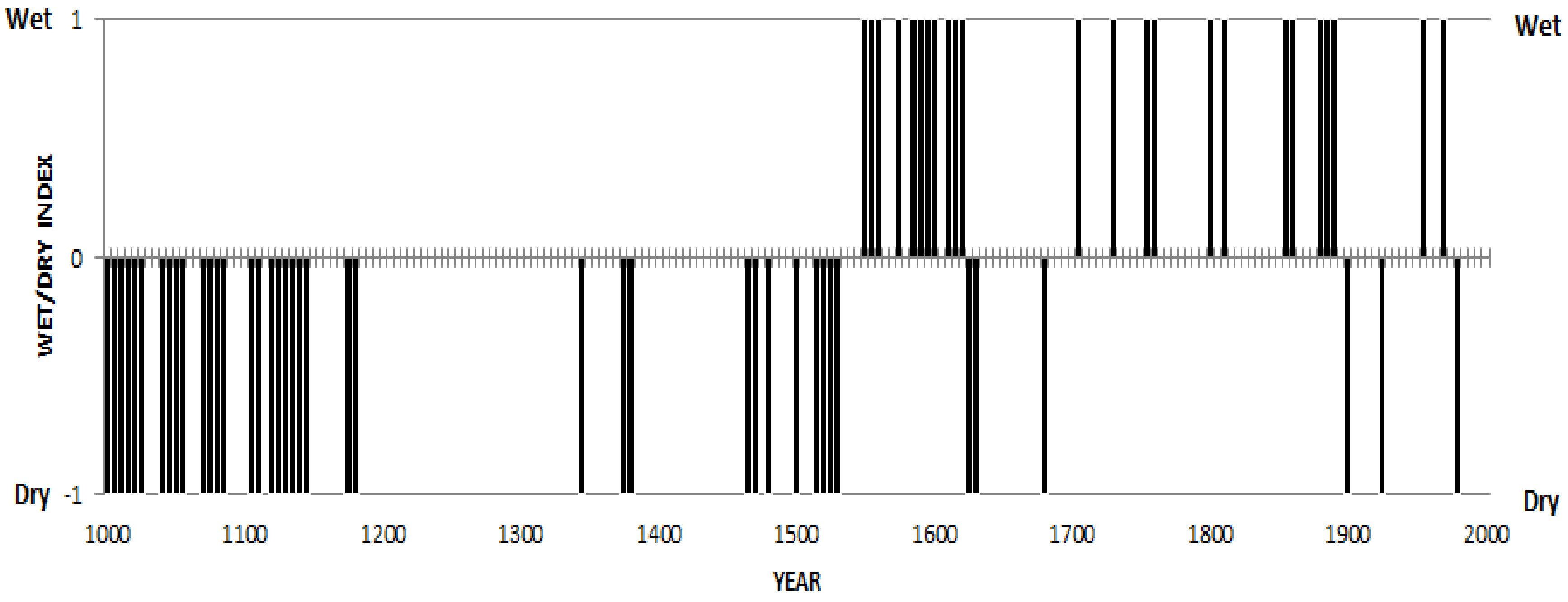
Occurrence of wet and dry epochs

Late 1500s/early 1600s appear to be very “wet” **(with clustering unlike anything seen in the instrumental period)**

Total records wet/dry composite index

Occurrence of wet and dry epochs

Very dry 1000-1200 **(again, unlike anything seen in the instrumental period)**



Total records wet/dry composite index

From Anna Flack's Honours (Nov 2015)

More recent palaeo work…Alternative Source of pre-instrumental info #4

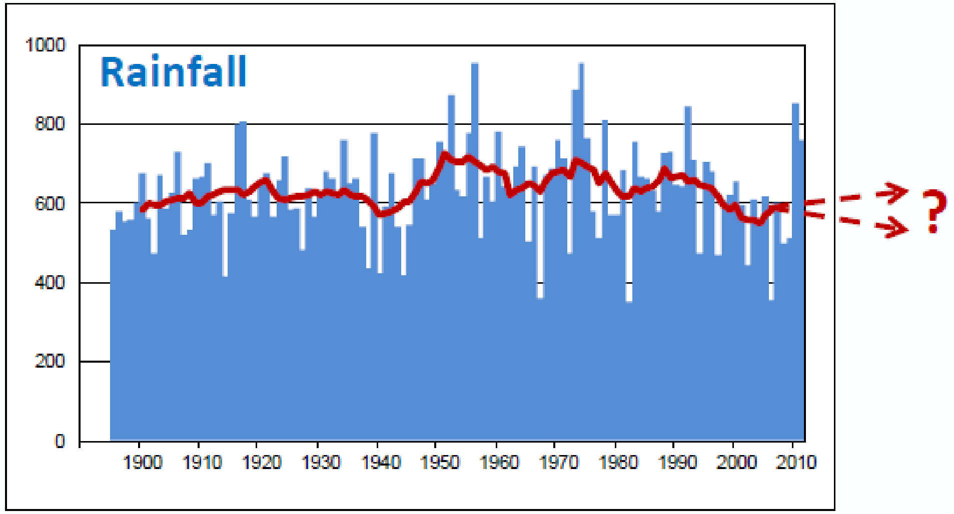
- ***Totally independent….people with no links to us, different palaeoclimate info, we weren't reviewers on the paper***
- 27 Feb 2019 – John Tibby & Cameron Barr (Uni. Adelaide) paper in Nature Scientific Reports:
  - Used preserved paper-bark tea tree leaves from North Stradbroke Island to get a 7000 year ENSO history.
  - Researchers found a generally wet period about 5,000 to 6,000 years ago – indicating a more consistent La Niña-like climate.
  - This changed to a more variable and increasingly drier climate about 3000 years ago – highlighting a strengthened El Niño phase.
  - There were substantial droughts during this strengthened El Niño phase, drier than the Millennium Drought (1997-2009).
  - *"…the probability of a drought worse than the Millennium Drought is much higher than the current prediction of one in 10,000 years.* ***Our rainfall reconstruction suggests that it may be as much as 10 times more likely****."*

More recent palaeo work…Alternative Source of pre-instrumental info #5

- ***Totally independent….people with no links to us, different palaeoclimate info, we weren't reviewers on the paper***
- 29 Feb 2019 – Buckley et al. "Interdecadal Pacific Oscillation reconstructed from trans-Pacific tree rings: 1000–2004" in Climate Dynamics.
  - Used tree rings from Vietnam
  - *"We reveal 15 positive and 15 negative phase shifts of the IPO prior to the period of instrumentation, suggesting that the IPO has been active for at least the past seven centuries with varying degrees of intensity."*
  - *"We compared our record to the Vance IPO record (Fig. 9) and we reveal generally strong agreement in spite of the vastly different nature of these two records."*

CLIMATE CHANGE

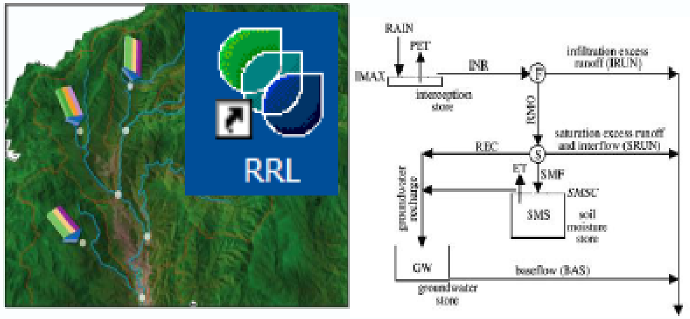
Modelling climate change impact on water



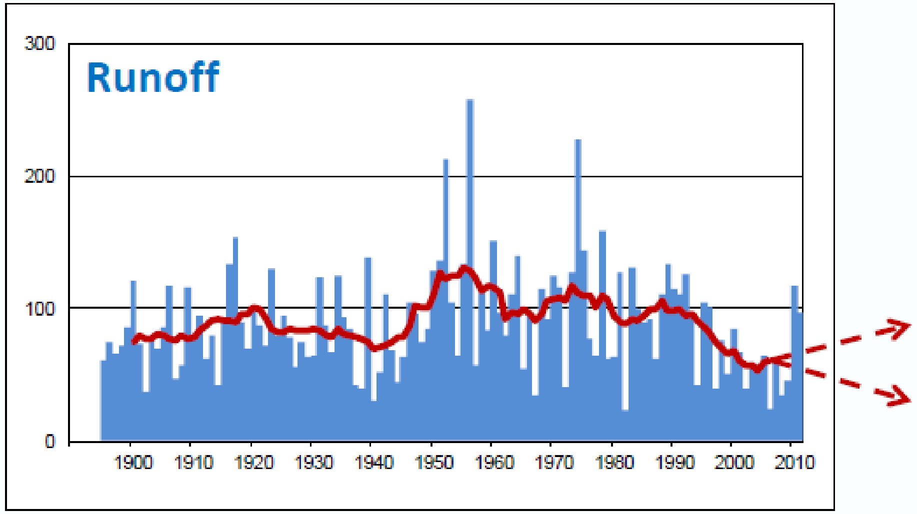
Construction of future rainfall (and climate) series

- Empirical scaling
- Statistical downscaling
- Dynamic downscaling

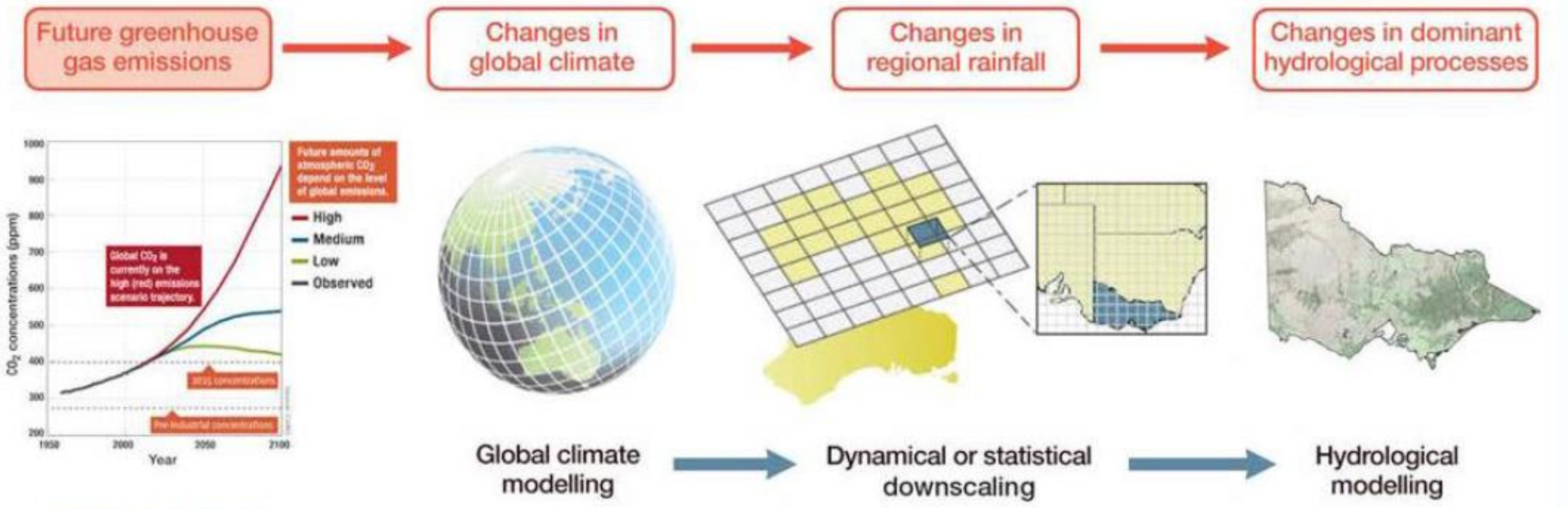
[Chiew et al., WRR, 2009]
[Mpelasoka & Chiew, JHydrometeorol, 2009]
[Potter et al., JHydrol, 2018]



Hydrological model



Sources of uncertainty in hydrological projections



- RCP2.6, RCP4.5, RCP6.5, RCP8.5
- Time horizons

Uncertainty in future rainfall projections

[Chiew et al., MODSIM, 2017]
[CSIRO & BoM, NRM Projections, 2015]
[Ekstrom et al., WIRES ClimChg, 2015]
[Ekstrom et al., Climate Services, 2016]

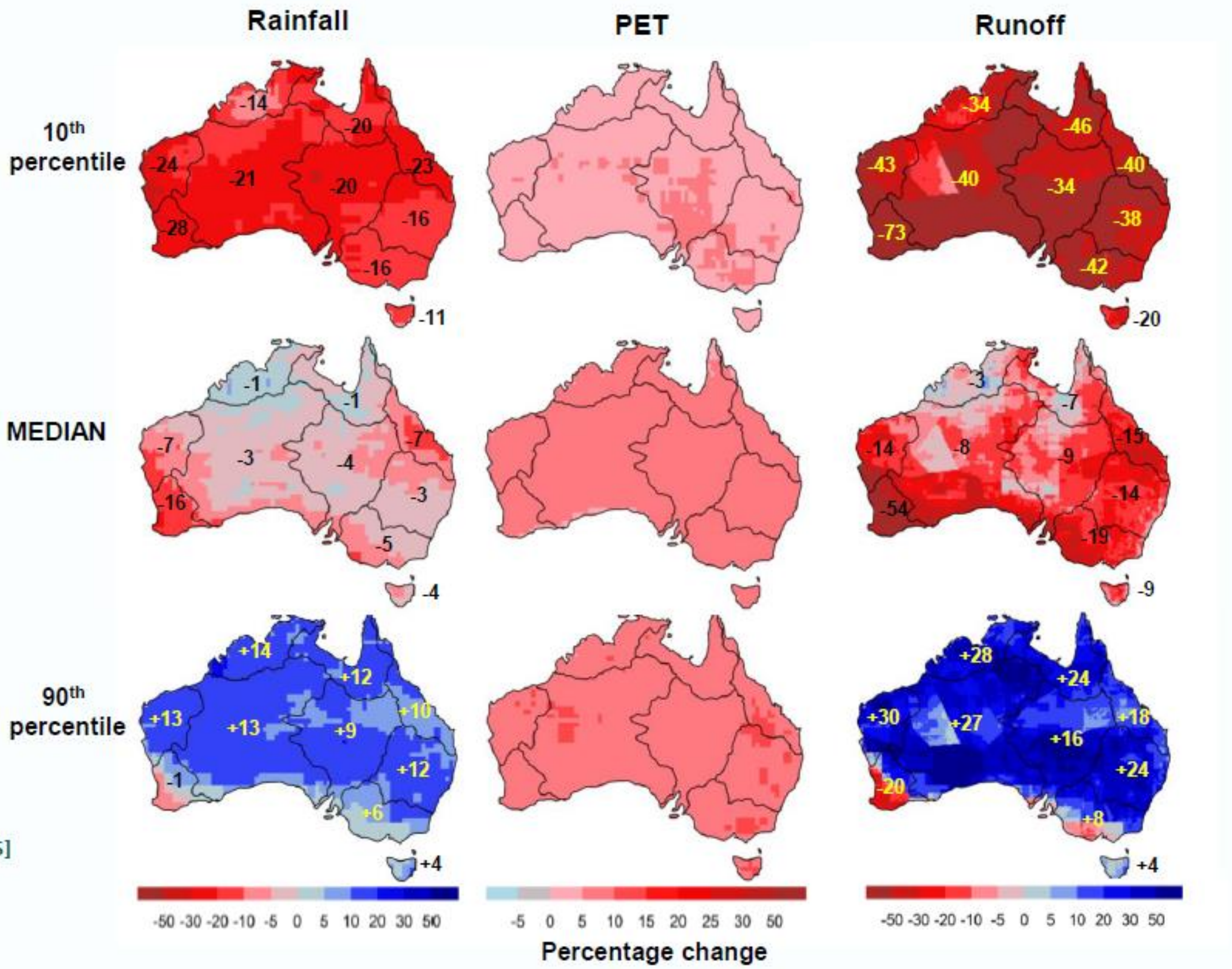
Rainfall (and climate) inputs for hydrological simulations

- Extrapolating to a future that is different from the past

Projections of future water availability

2046–2075 relative to 1976–2005 for RCP8.5

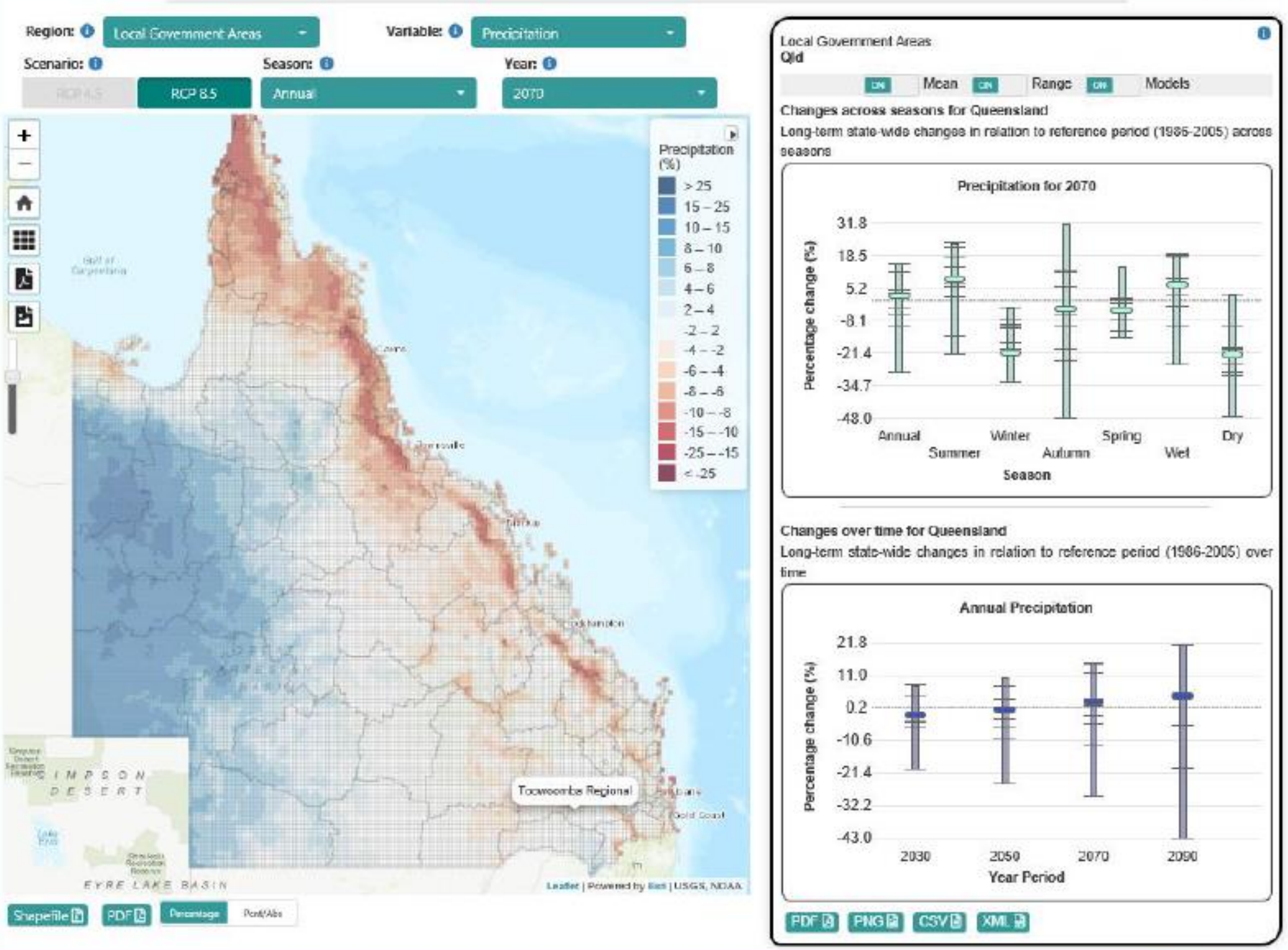
[Hydrological modelling informed by projections from 42 CMIP5 GCMs]



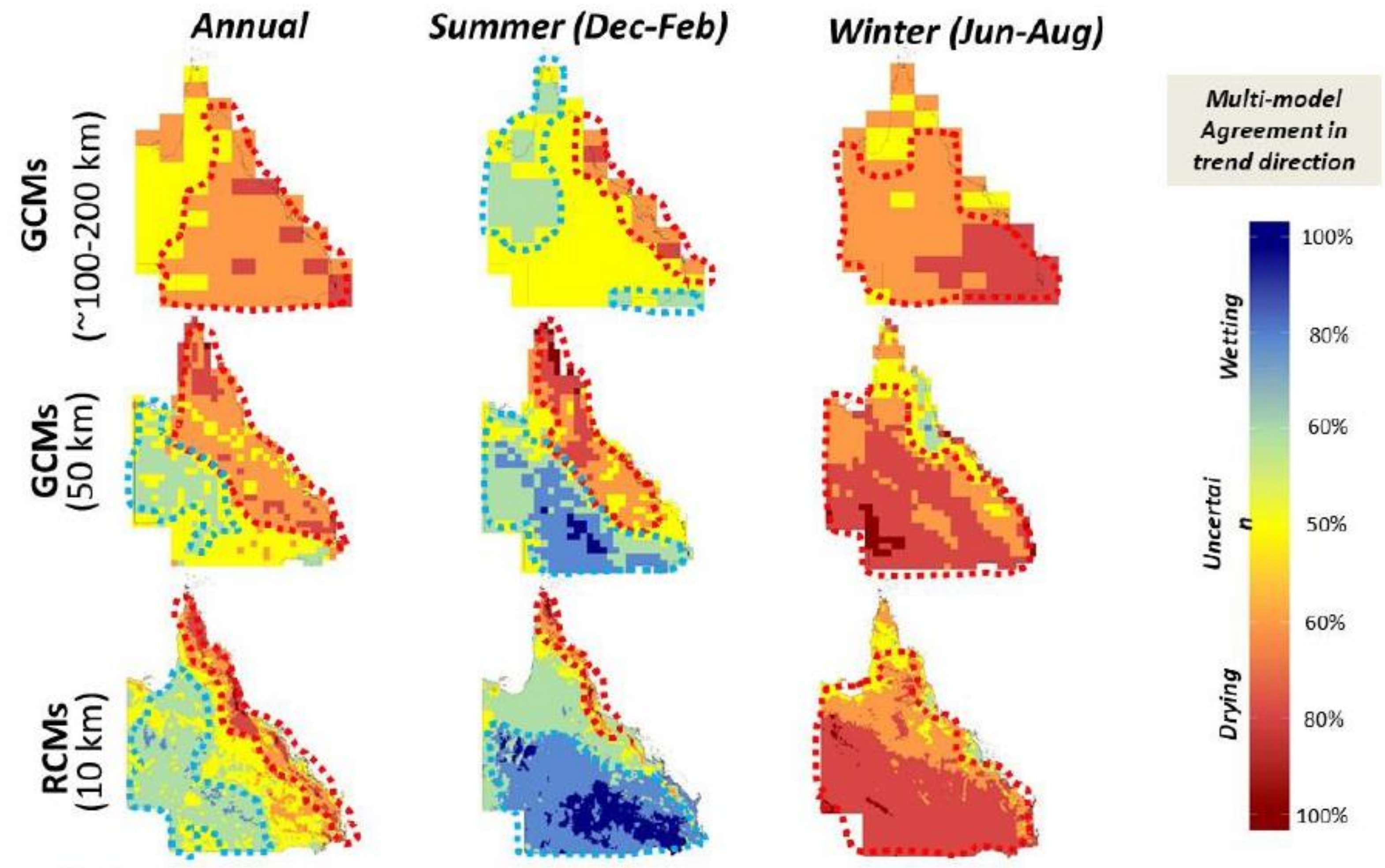
[Chiew et al., MODSIM, 2017]
[CSIRO & BoM, NRM Projections, 2015]
[Teng et al., JHydrometeorol, 2012]

High resolution climate projections for Queensland

Queensland Future Climate Dashboard
https://app.longpaddock.qld.gov.au/dashboard/



Future rainfall projections for Queensland



[Hoffman et al., JGR, 2016]

Queensland Future Climate Dashboard
https://app.longpaddock.qld.gov.au/dashboard/

Future hydroclimate projections for north-east Australia

Temperature

- Temperature will increase (and therefore also hot days, PET, water demand, etc…).

Rainfall

- Winter rainfall is likely to decrease.
- Low confidence in annual rainfall projections
  [-25% to +15% in eastern Australia, -25% to +20% in far north-east (by 2090 for RCP8.5)]
- Natural climate variability will dominate in the near-term.

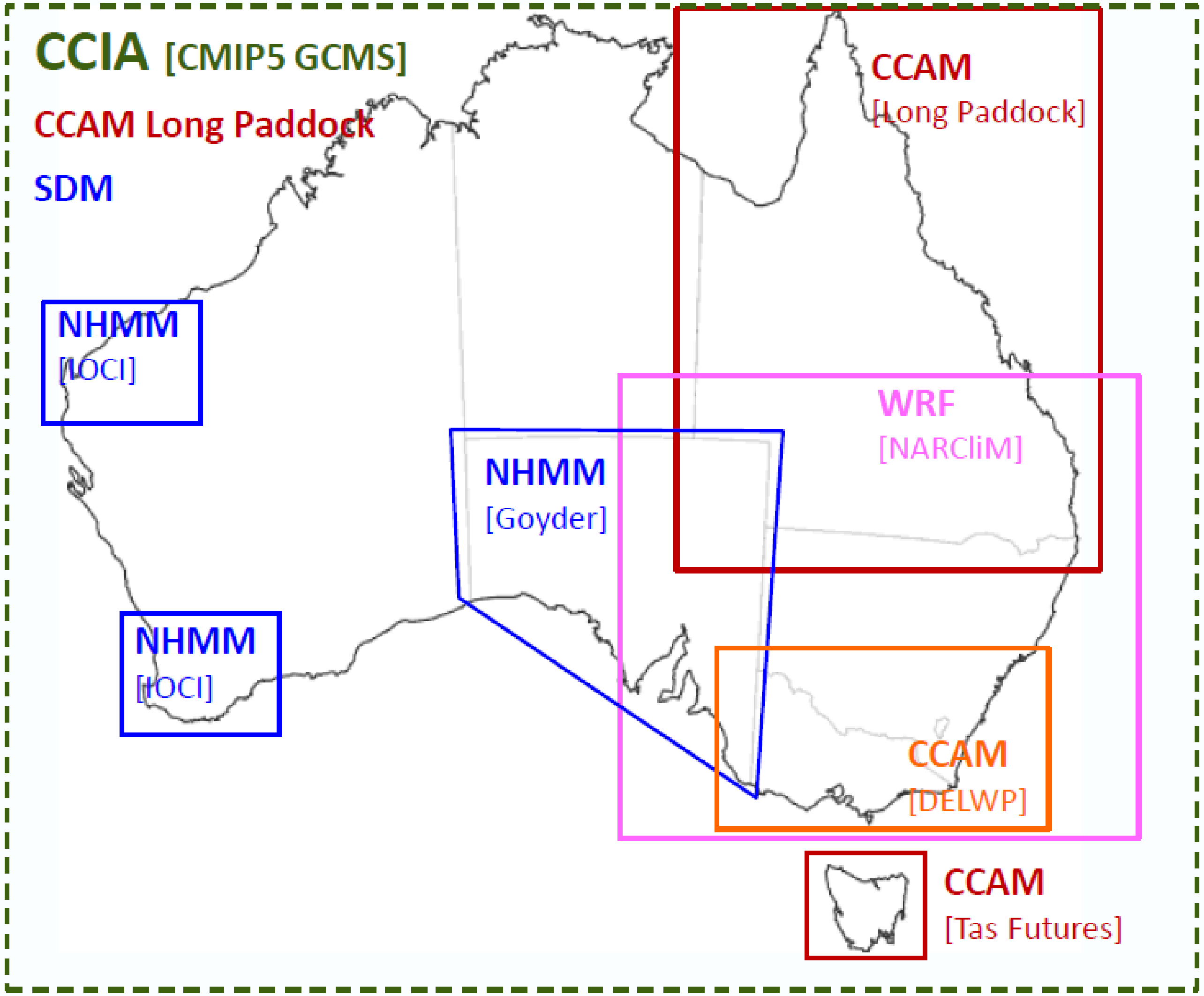
Runoff (and water availability)

- Modelled projected change in mean annual runoff range from -40% to +20% for 2°C global average warming.

Extreme rainfall and flood risk

- Extreme high rainfall will be more intense.
- Design rainfall intensity will increase by 5% to more than 10% for shorter duration and longer return period storms.
- Enhanced flood risk (in northern Australia).

Climate projection data sources and products



Coming soon .....

CMIP6 GCMs

RCMs (CORDEX)

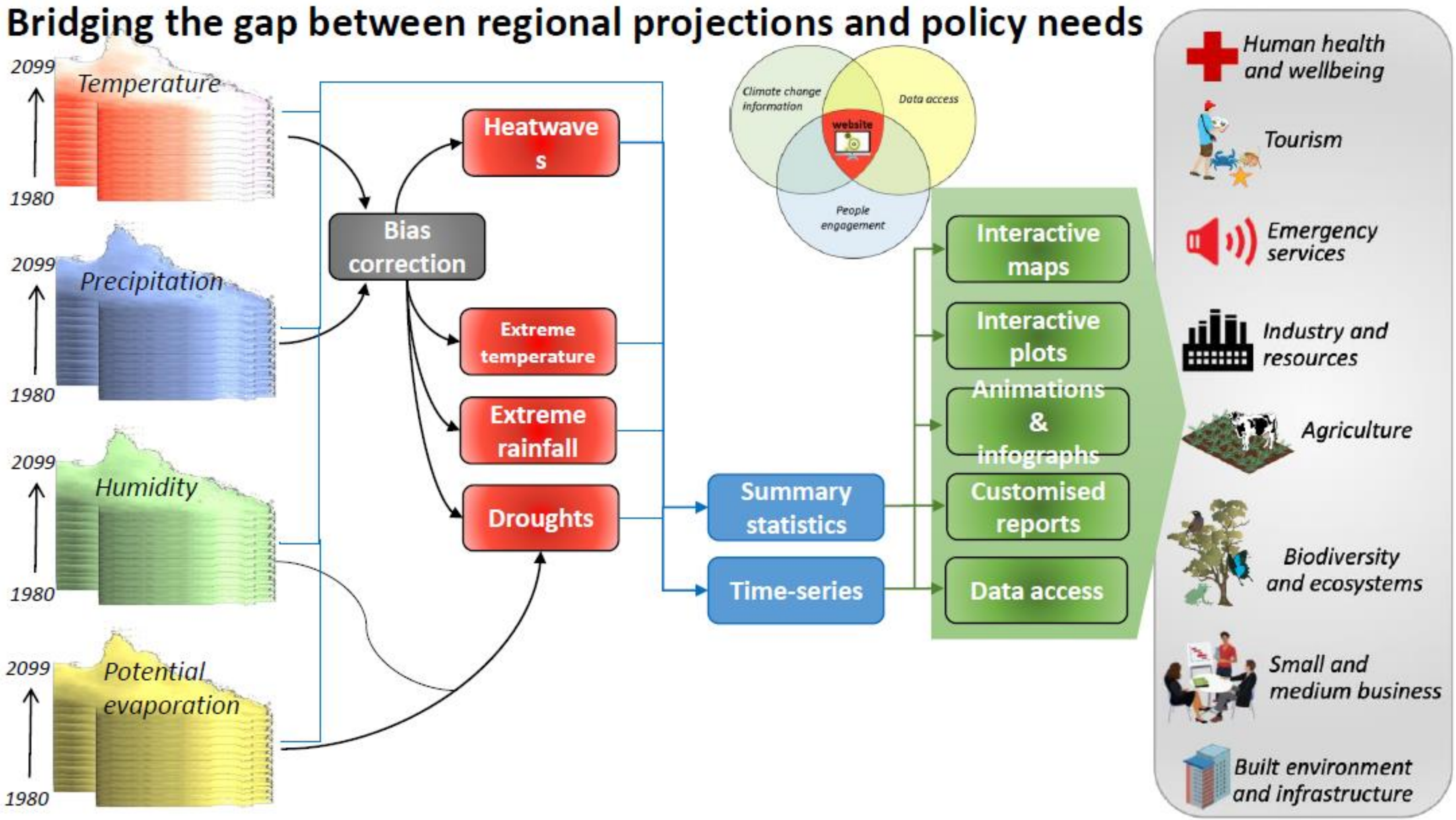
Dynamic downscaling
Statistical downscaling

NESP ESCC

BoM Hydrological Projections

High resolution climate change projections: web portal, data & information

- Main page: https://app.longpaddock.qld.gov.au/
- Understanding Future Climate: https://app.longpaddock.qld.gov.au/climateFacts/
- Queensland Future Climate dashboard: https://app.longpaddock.qld.gov.au/dashboard/
- Heatwaves case study: https://app.longpaddock.qld.gov.au/heatwave/
- Water-security case study: https://app.longpaddock.qld.gov.au/water/
- TERN data: https://app.longpaddock.qld.gov.au/tern.html
- Direct link http://dap.tern.org.au/thredds/catalog/CMIP5QLD/catalog.html


Bridging the gap between regional projections and policy needs
2099
Temperature
1980
2099
Precipitation
1980
2099
Humidity
1980
2099
Potential evaporation
1980
Bias correction
Heatwaves
Extreme temperature
Extreme rainfall
Droughts
Climate change information
Data access
website
People engagement
Summary statistics
Time-series
Interactive maps
Interactive plots
Animations & infographs
Customised reports
Data access
Human health and wellbeing
Tourism
Emergency services
Industry and resources
Agriculture
Biodiversity and ecosystems
Small and medium business
Built environment and infrastructure

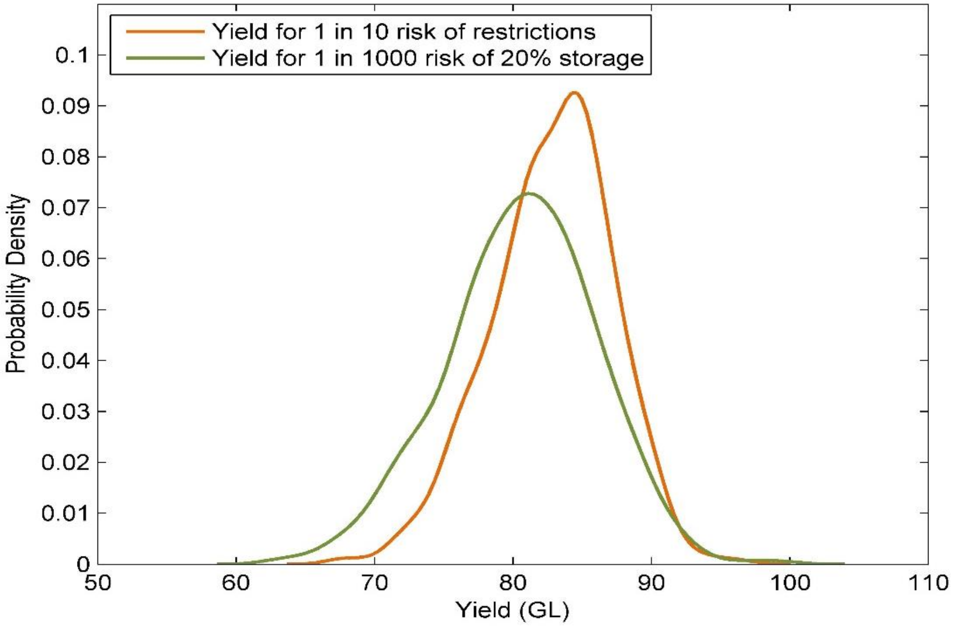
Summary and conclusions

- Extensive set (11 downscaled CMIP5 models) of high-resolution (10km) climate projection for RCP8.5 & RCP4.5 for Queensland & 50 km global.
- Data portal with projections in mean climate, heat waves, extreme indices and SPI drought is available at https://www.longpaddock.qld.gov.au/qld-future-climate/
- High-resolution projections are largely consistent with CMIP5 projections.
- Projection show increase in temperature related extremes such as heat wave duration & frequency, warm spell duration and no of hot days and nights.
- Rainfall based extreme indices point to increase in both dry and wet extremes, with stronger tendency towards multi-year precipitation deficits and aridity increase (PET/Pr)
- Raw and bias corrected daily data available

WHAT DOES IT MEAN FOR WATER MODELLING?

What does it mean for water modelling?

- Newcastle/Hunter urban water supply example – but issues are similar elsewhere



From Berghout et al. (2017). Distribution of annual yield (GL) for which the water supply system meets 1-in-10 restriction and 1-in-1000 year water security criteria.

Yield = max. volume of water that can be extracted for given risk level
Annual demand has to be less than annual yield!!

Based on existing stochastic and water modelling that just uses instrumental data (113yrs, 1904-2016):
--Best estimate for yield is ~80GL/year
--But uncertainty is +/-20GL/year (~50% of best estimate)

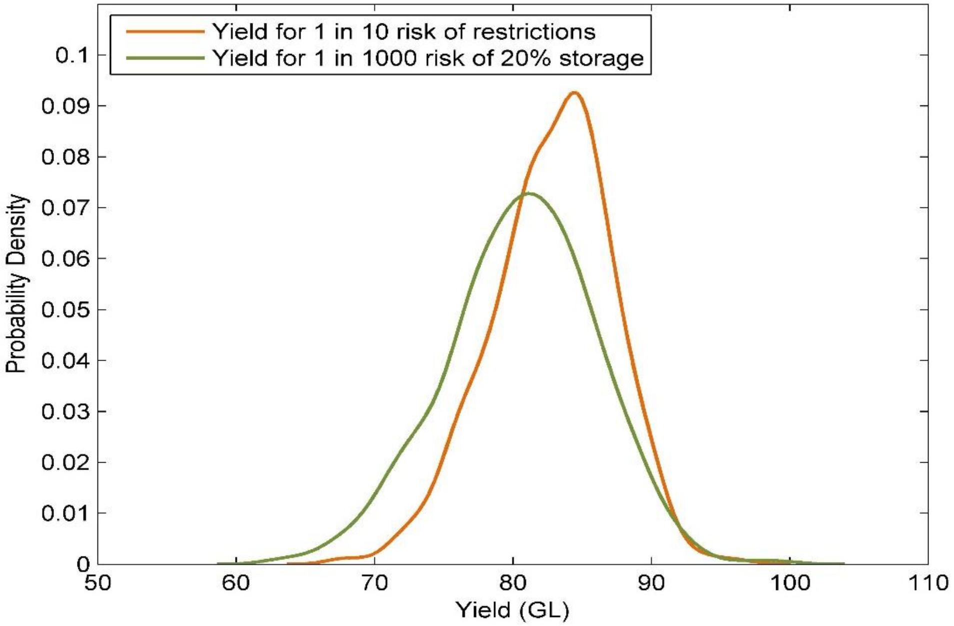
Reason for the uncertainty: not enough info in the instrumental rain and flow data to realistically characterise multiyear drought in the hydro/stochastic models.

How bad can it get?

- Current demand ~75GL/year (but increasing at ~0.5%/year)
- Using 113yrs instrumental data (and assume climate stays same):
  - Yield < current (2016) demand is possible now
  - Demand on track to exceed Yield best estimate by ~2029

What does it mean for water modelling?

- Newcastle/Hunter urban water supply example – but issues are similar elsewhere



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Annual demand has to be less than annual yield!!

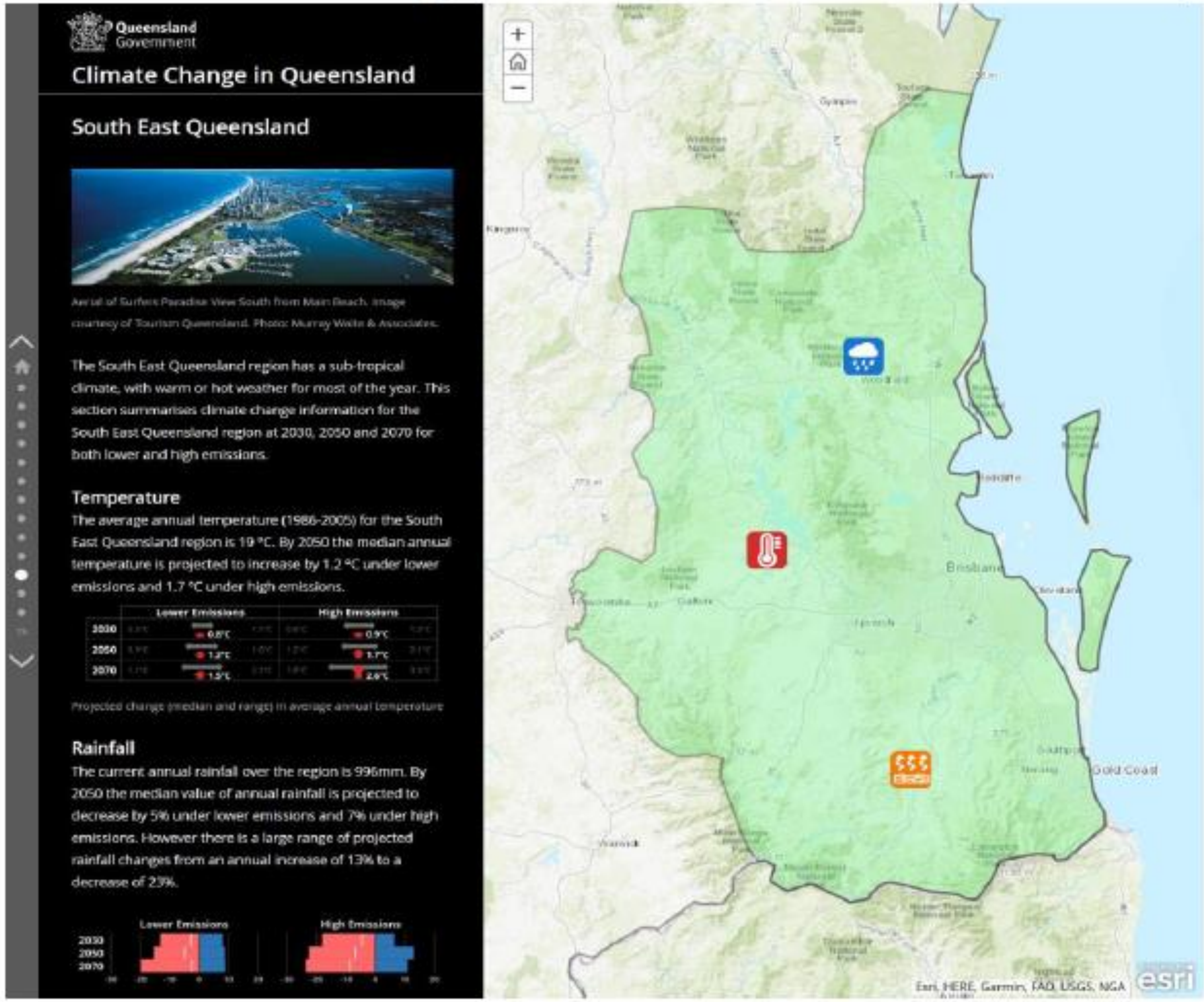
How can climate variability and change science help?

- palaeoclimate and/or climate model data = longer records = more variability & more examples of drought/flood to calibrate hydro models => less uncertainty about yield estimates
- better understanding into mechanisms that cause flood/drought
  - better insights into how bad things can get
  - provides targets to test models…if models misrepresent magnitude or likelihood of extremes we know have occurred then need to be careful using them for planning, policy etc.
- for successful adaptation and high resilience you first need proper understanding into the range of impacts that are plausible
  - incorporating future climate change impacts is an important part of this…..but it is also critical to make sure baseline (i.e. current) risk estimates are realistic and adequately dealt with!!

Thank you

- Any questions…
- Anthony.Kiem@newcastle.edu.au

Climate Change in Queensland 2017 web portal to support Q-CAS



13 regional planning areas with summary of change at 2030, 2050 and 2070 for key parameters (temperature, rainfall, potential evaporation, wind speed, relative humidity & solar radiation based on data from CMIP5/NRM global models for RCP8.5 and RCP4.5

Consistent Climate Scenarios (CCS) – data for biophysical modelling

Home | About | Drought Declaration | Drought & Climate Adaptation | Southern Oscillation Index | Climate Outlooks, Weather & Fire | SILO | AussieGRASS Rainfall / Pasture | FORAGE Property Reports | Queensland Future Climate | Rainfall Posters

Queensland Future Climate

Understanding Future Climate

Future Climate Dashboard

Adapting to Future Climate

- Heatwaves case study
- Water security case study
- The Climate Change Risk Matrix
- Climate Impact and Adaptation

Data and Information

- High Resolution Projections Data
- ▸ Biophysical Modelling (CCCS)
  - User Guide

Additional Resources

Home / Queensland Future Climate / Biophysical Modelling (CCCS)

Biophysical Modelling (CCCS) - Data Order Form

Climate projections are available as daily time-series in a format suitable for most biophysical models. The projections data are provided for two time-slices centred on 2030 and 2050, and are available for approximately 4,700 climate stations, or for points on a 0.05 degree (approximately 5km) grid across Australia. See **user guide** for details about Consistent Climate Change Scenarios data.

Six climate elements (rainfall, evaporation, minimum and maximum temperature, solar radiation and vapour pressure deficit) are supplied in either P51 or APSIM format, which are data input details specific to GRASP pasture model (P51) and APSIM crop simulation model.

The data are available for

- three perturbation methods (change factor, quantile matching and linear mixed effect state space) for Australia and high resolution downscaled 10 km data for Queensland.
- eight emission scenarios used in the 4th Assessment Report (AR4) of IPCC. These emission scenarios are described in the Special Report on Emissions Scenarios (SRES). The data for the following scenarios are available: A1FI, A2, A1B, B2, A1T, B1, 550ppm stabilisation by 2150 and 450ppm stabilisation by 2100.
- four Representative Concentration Pathways (RCPs) for the 5th Assessment Report (AR5) of IPCC (RCP2.6, RCP4.5, RCP6.0 and RCP8.5)
- three global sensitivities (high, medium and low)
- 23 global climate models for AR4
- 32 global climate models for AR5.
- 10 high resolution climate models downscaled to 10 km of spatial resolution over Queensland region.

Data are delivered via ftp. A sample of the data (ZIP, 1.3M) is available.

Only small orders for data can be accepted via this web site. For example, you can only download data for up to ten locations and up to three emission scenarios at any one time. If you wish to order larger amounts of data, please contact us.

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