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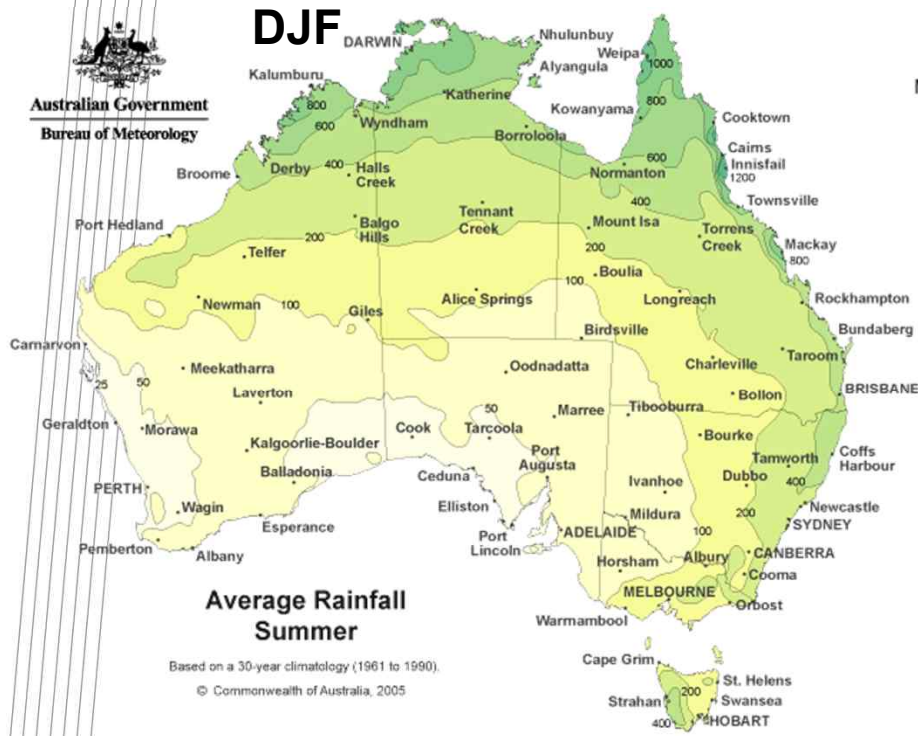
## Did climate change induced rainfall trends contribute to the Australian Millennium drought?

**Dr Wenju Cai**

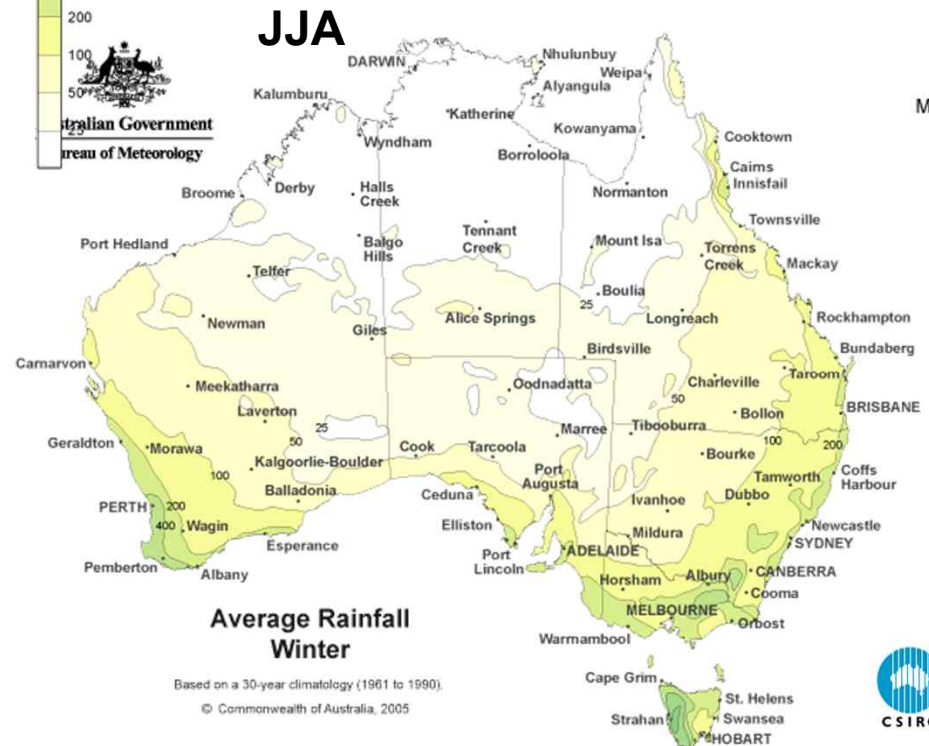
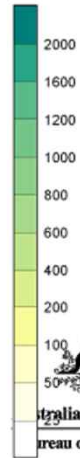
**CSIRO Marine and Atmospheric Research**



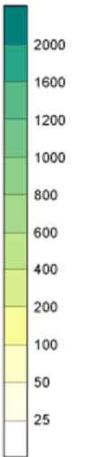
# Seasonality of rainfall



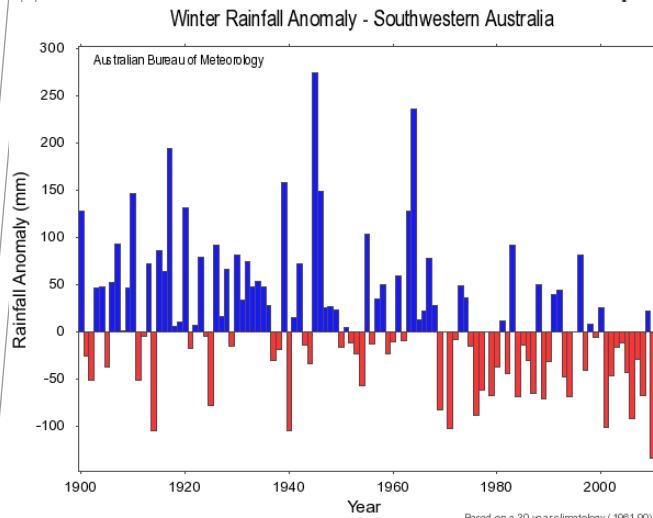
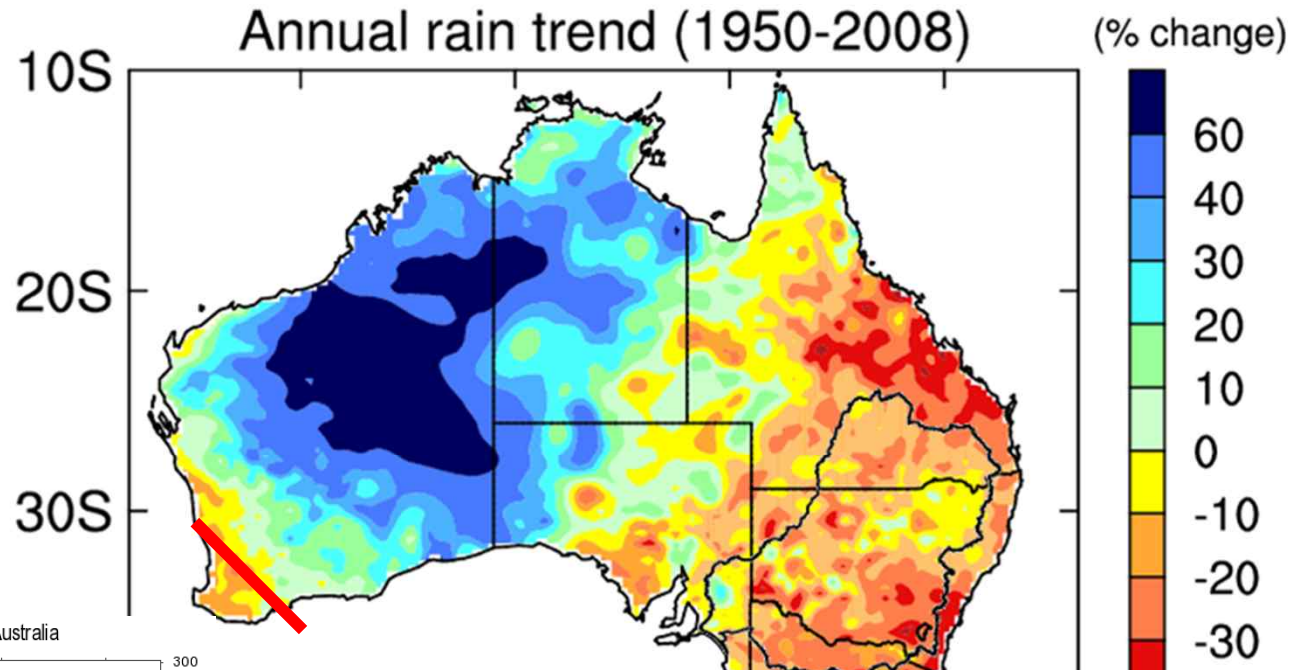
Millimetres



Millimetres

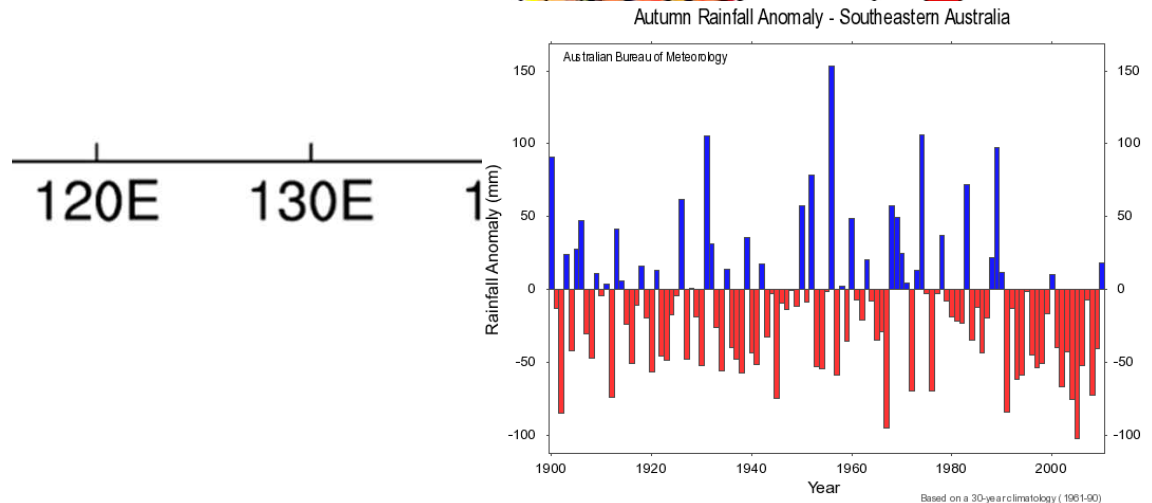


# Annual rainfall trends since 1950 in % of climatology



Based on a 30-year climatology (1961-90)

CSIRO. The Australian Drought

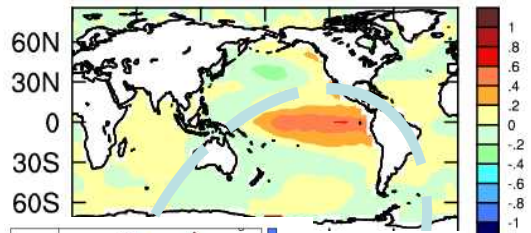


Based on a 30-year climatology (1961-90)

# Does climate change exacerbate the severity ?

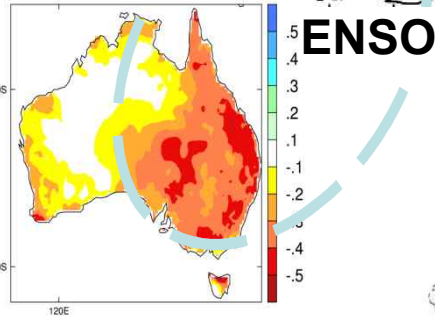
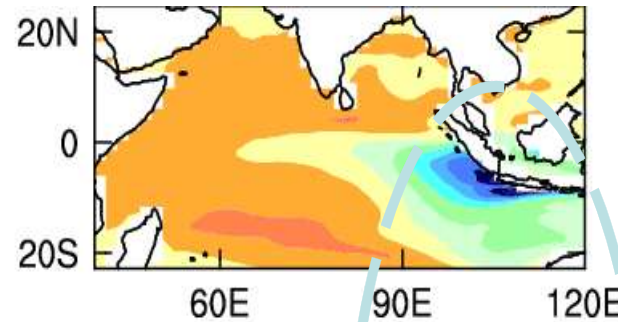
- What causes the drought?
- It is essential to understand the drivers of rainfall variability

# The three-headed dog of the Australian climate

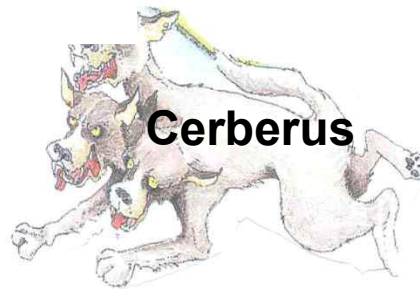


All year

## Indian Ocean Dipole: IOD

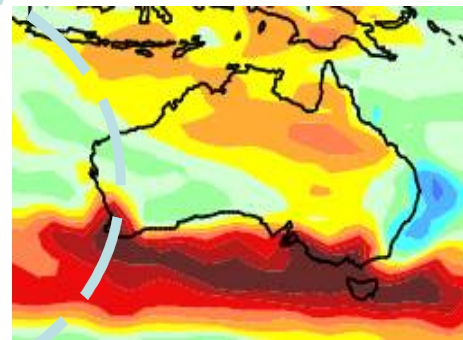
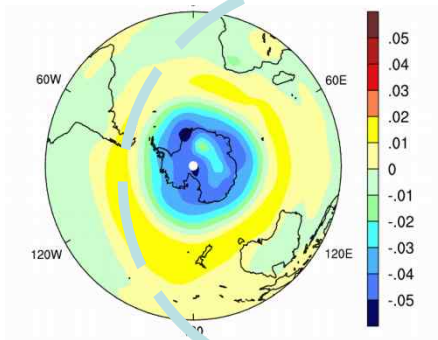


ENSO

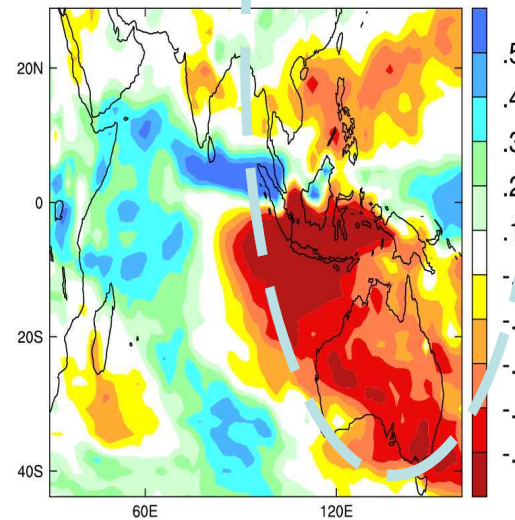


Cerberus

## Southern Annular Mode: SAM



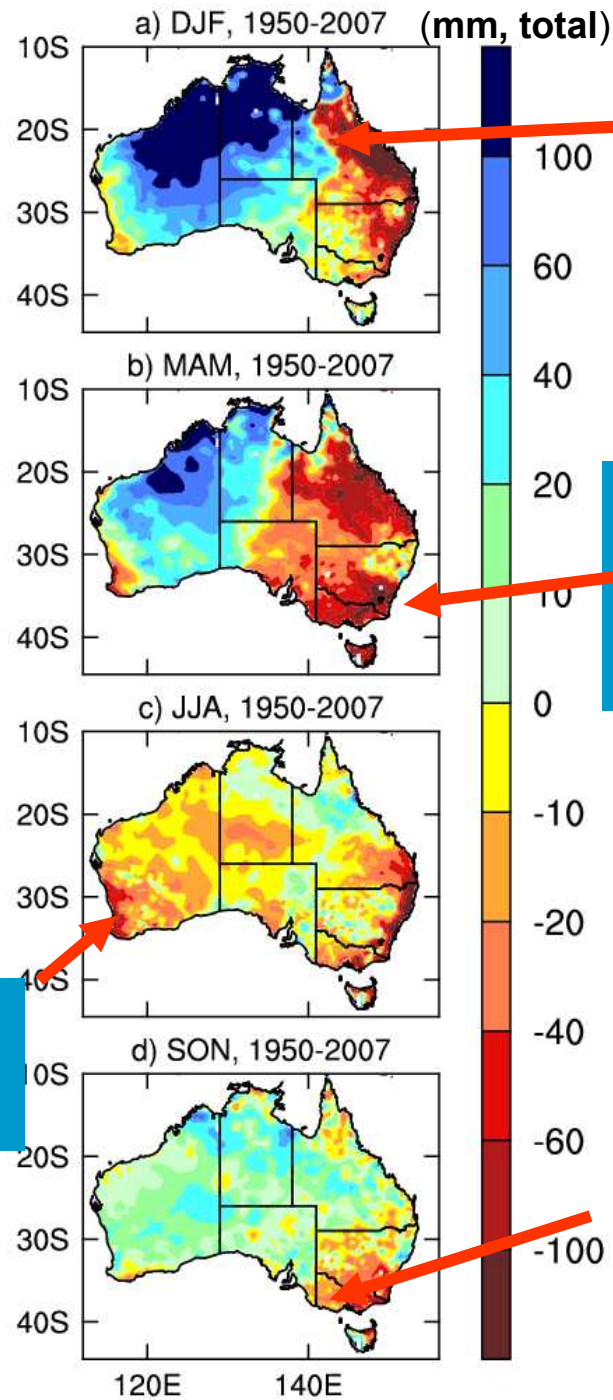
Winter



Winter & Spring

# Does climate change exacerbate the severity?

- What causes the drought?
- It is essential to understand the drivers of rainfall variability.
- Seasonality is important



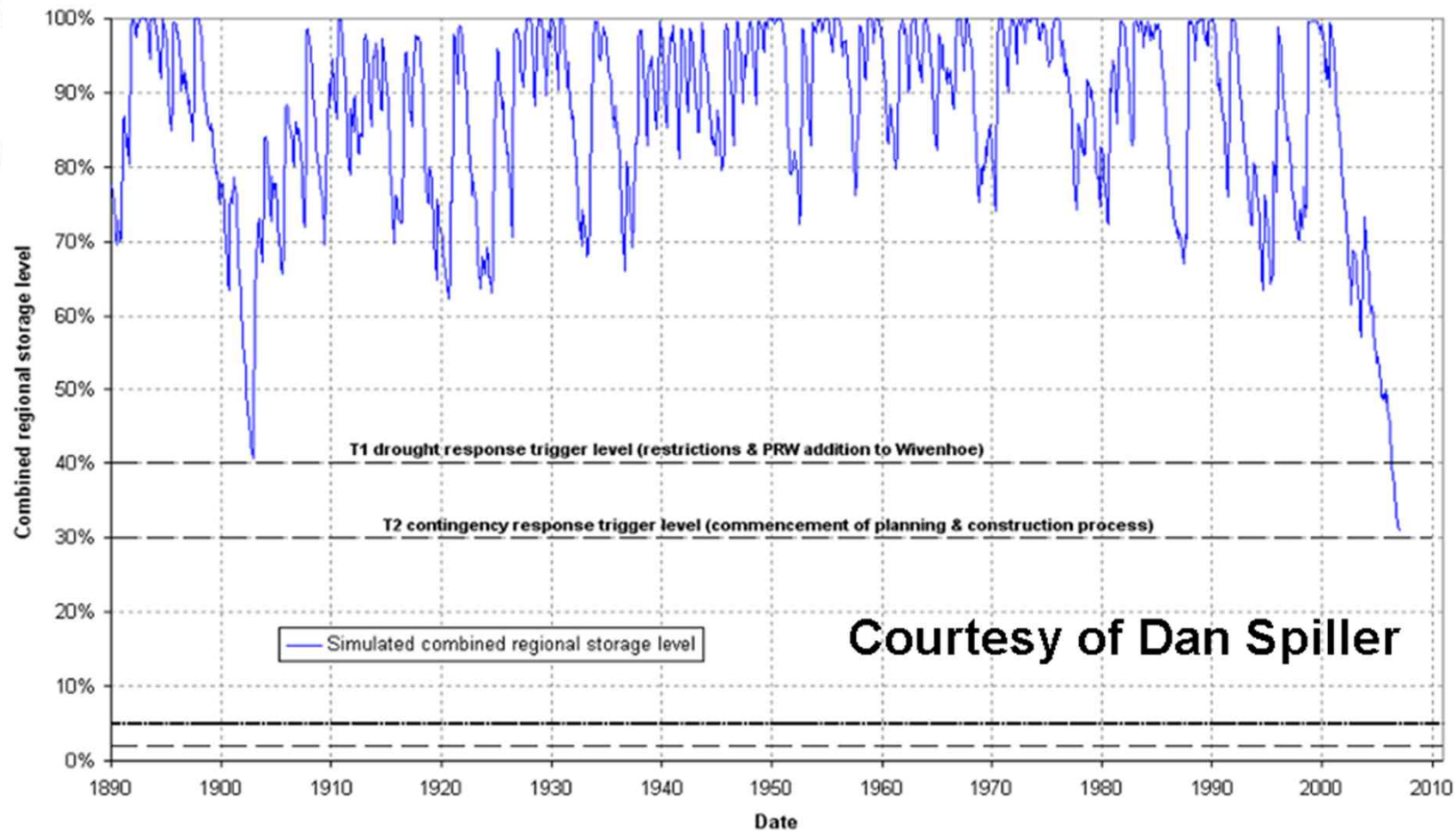
ENSO Impact  
asymmetry → the  
PDO & Climate  
Shift

We don't under  
stand the  
dynamics

Positive SAM  
trend

More positive  
IODs

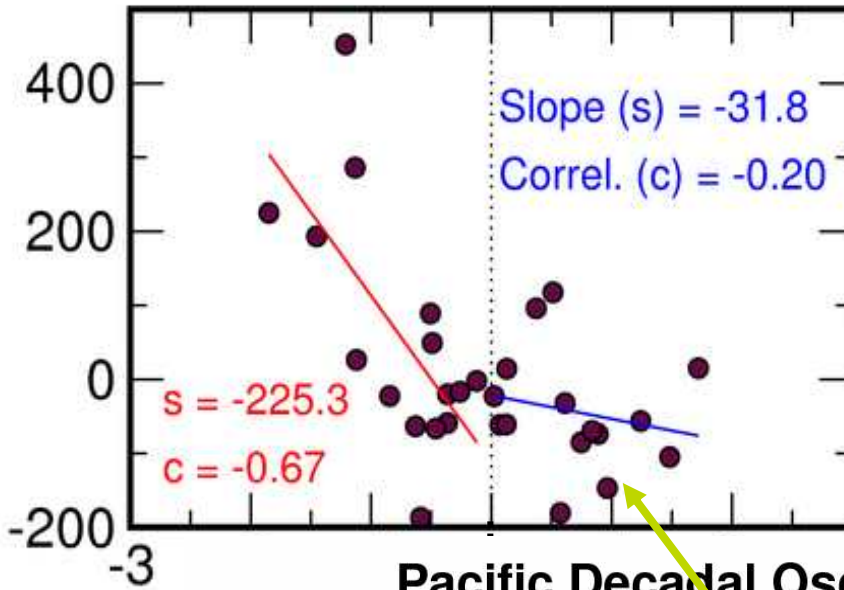
# Time sequence of SEQ water storage level from 1890-2009



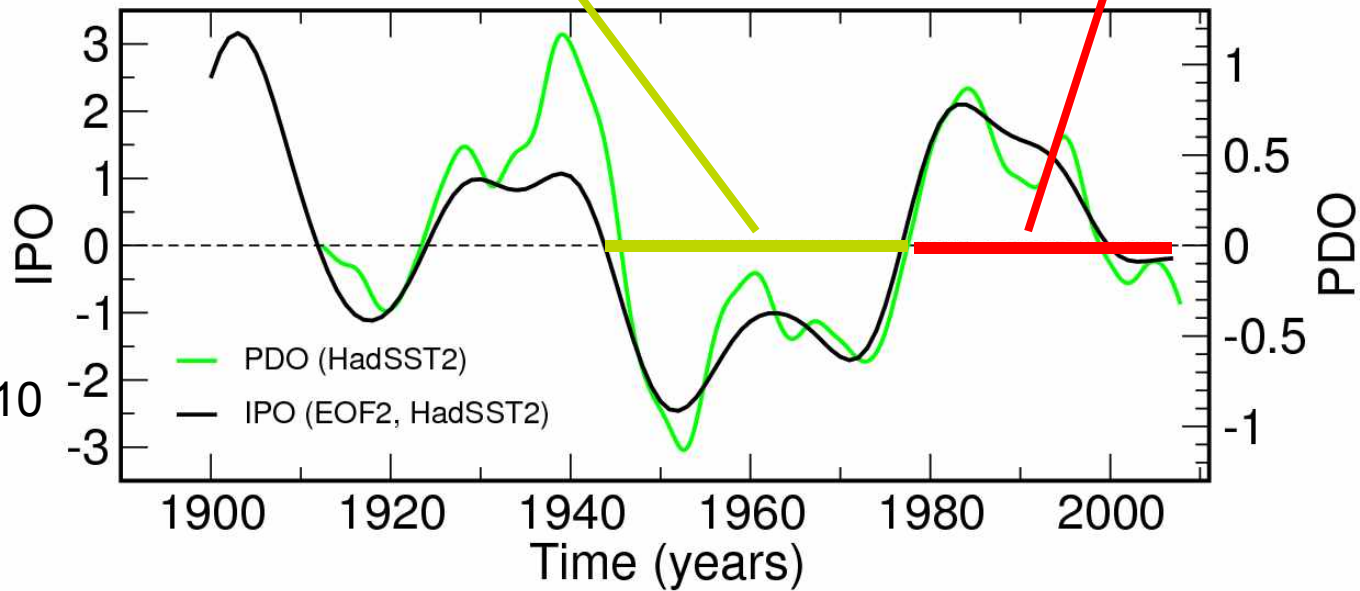
# 1950-1979

(a) NINO3.4 & SEQ Rainfall

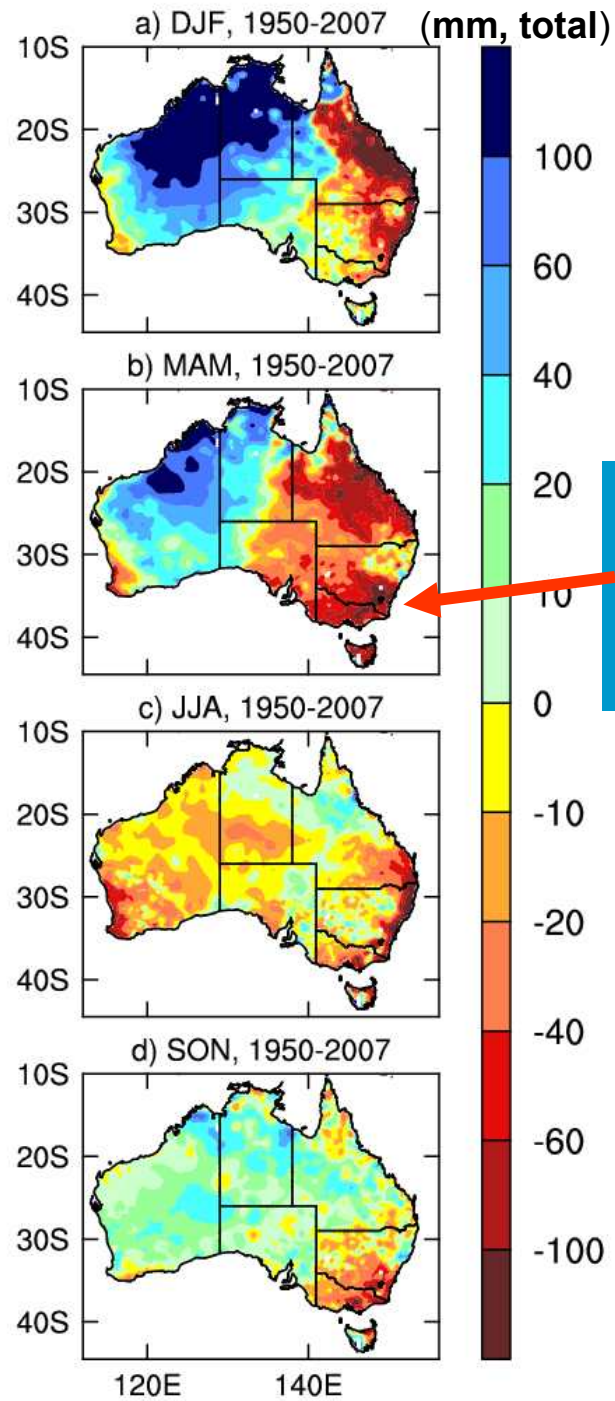
SEQ Rainfall anomaly (mm)



## Pacific Decadal Oscillation (PDO) & Interdecadal Pacific Oscillation (IPO)



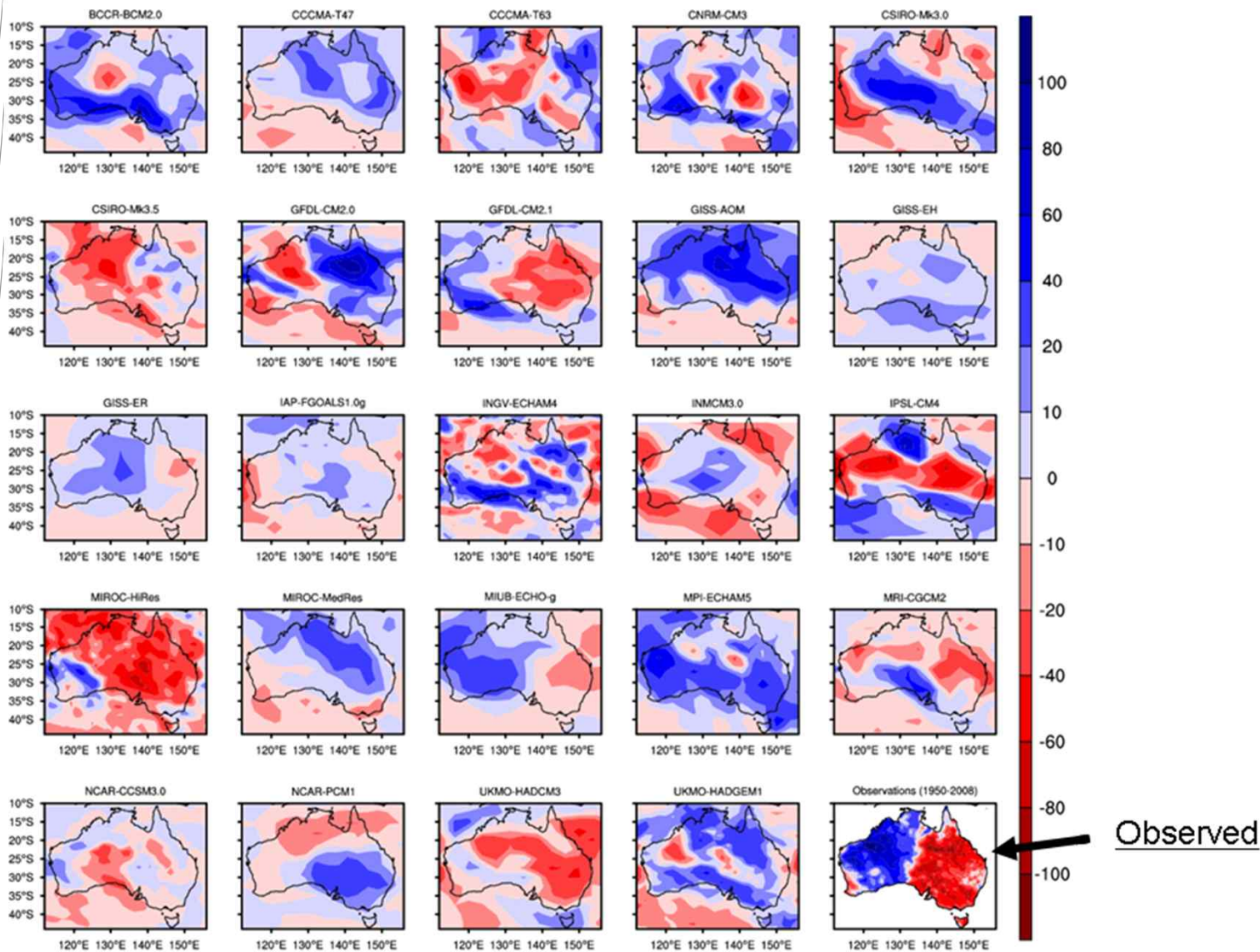
Cai et al. 2010



We don't understand the dynamics

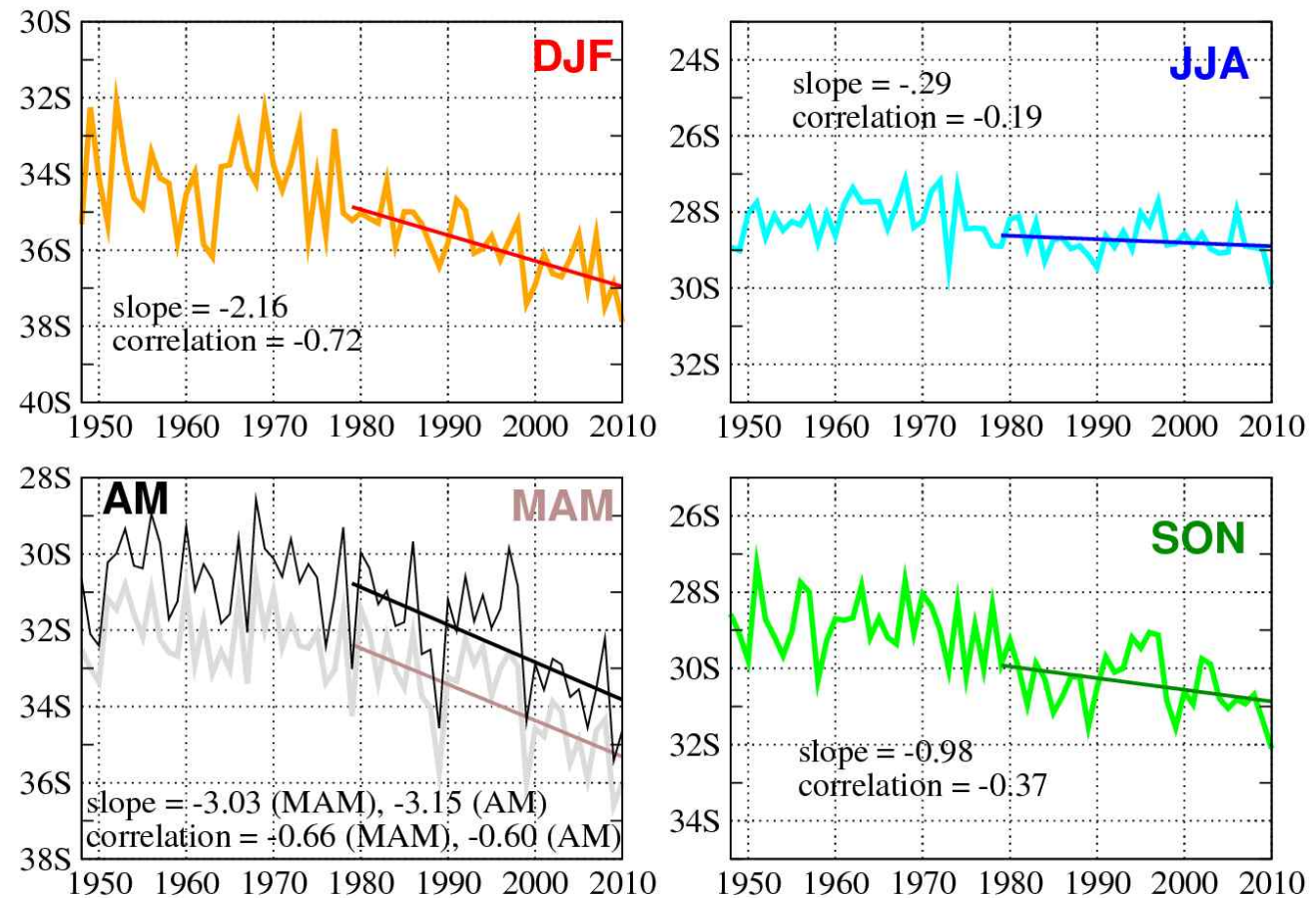
# Lack of consensus in IPCC-class models

CMIP3 model Australia rainfall trends (1950-1999, MAM)

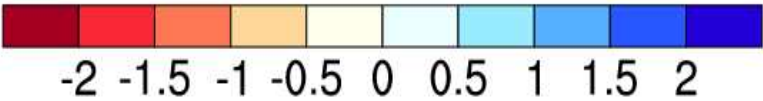
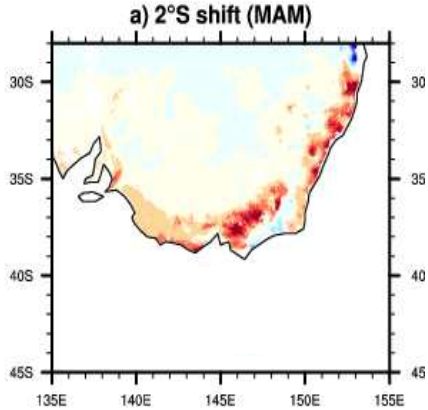
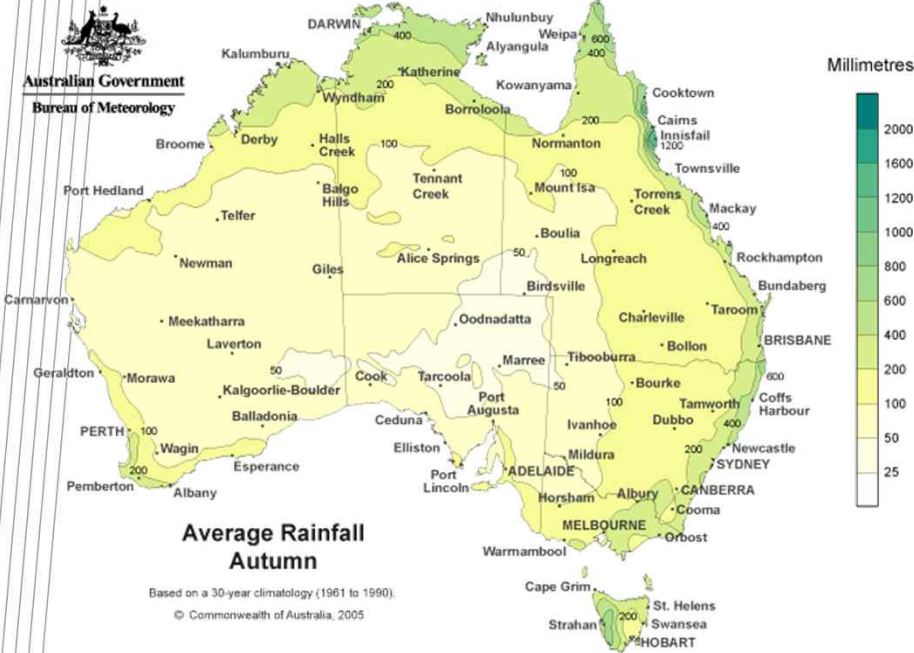


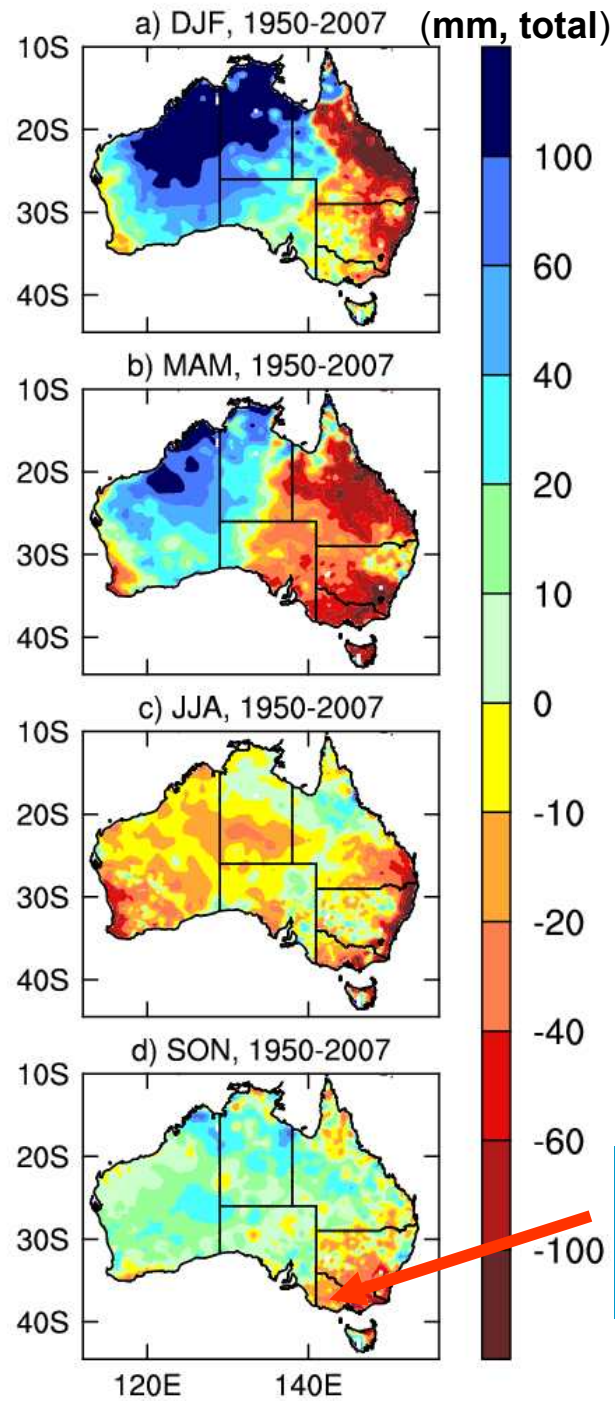
# Hadley cell edges

Extent of SH Hadley Cell (Zero zonal MMS<sub>500</sub>, NCEP1)



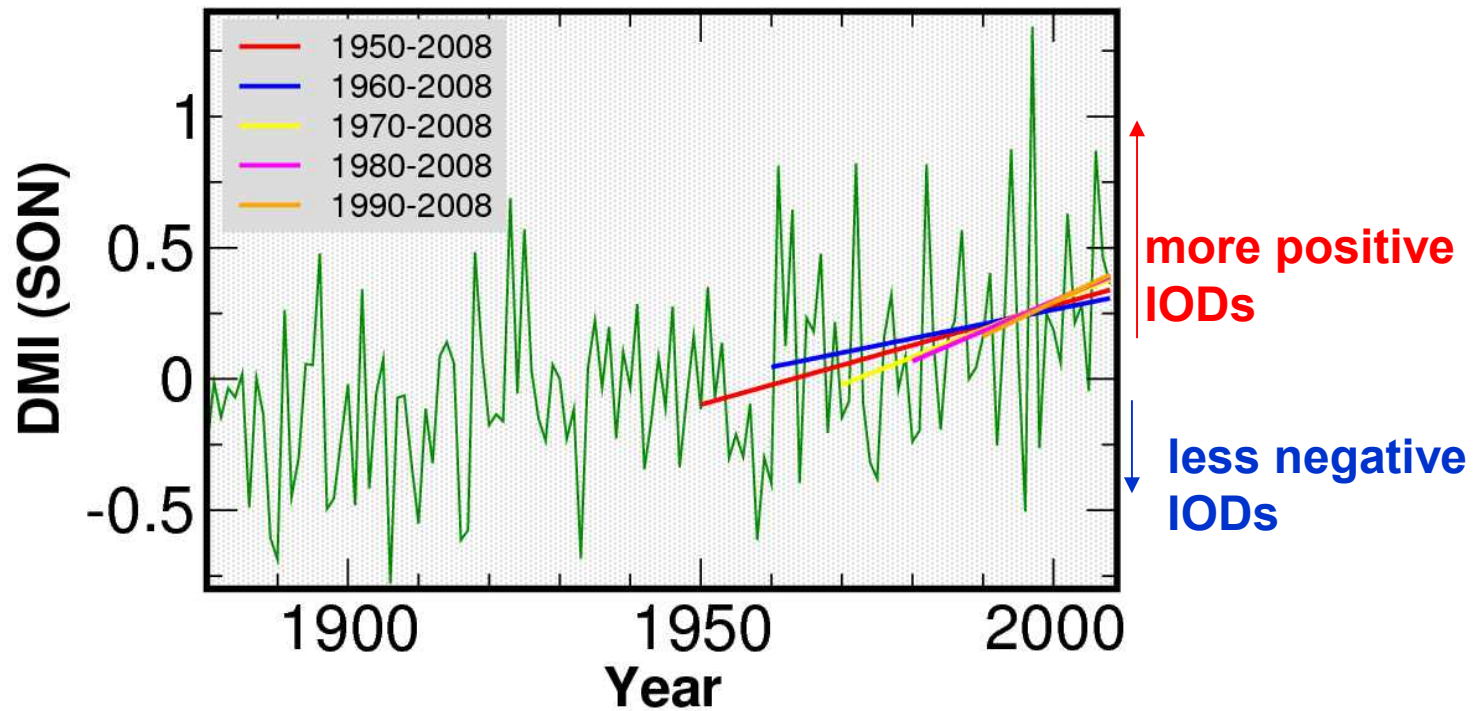
# Changes due to a 2° poleward shift of climatological MAM rainfall





More positive  
IODs

# The IOD is trending up

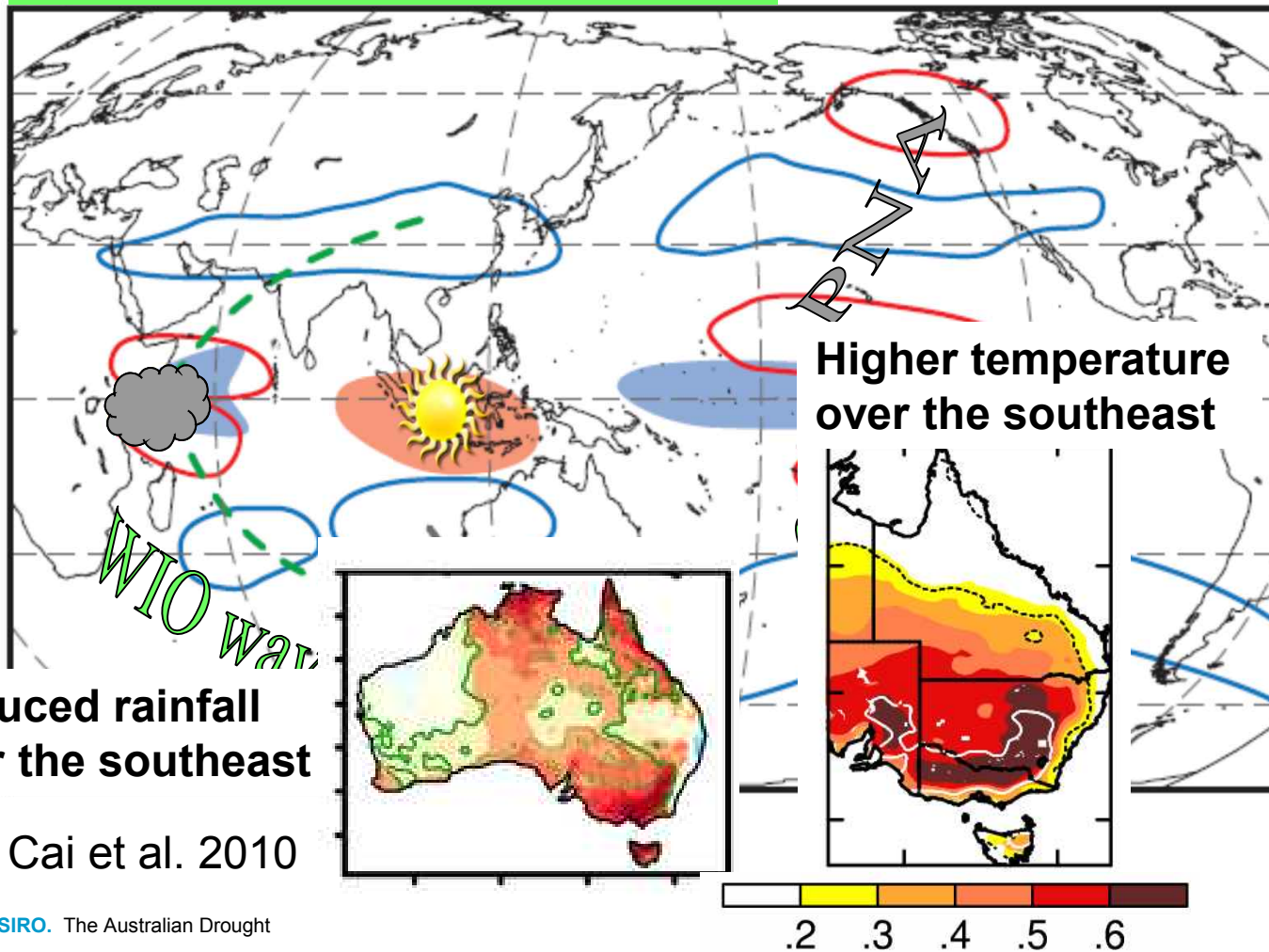


**Recent positive IOD years: 2002, 2004, 2006, 2007, 2008**

Cai et al. 20103, *Nature Geoscience*

# Mechanism of the IOD and ENSO impact on Australia rainfall: SON

## SON: IOD + El Niño



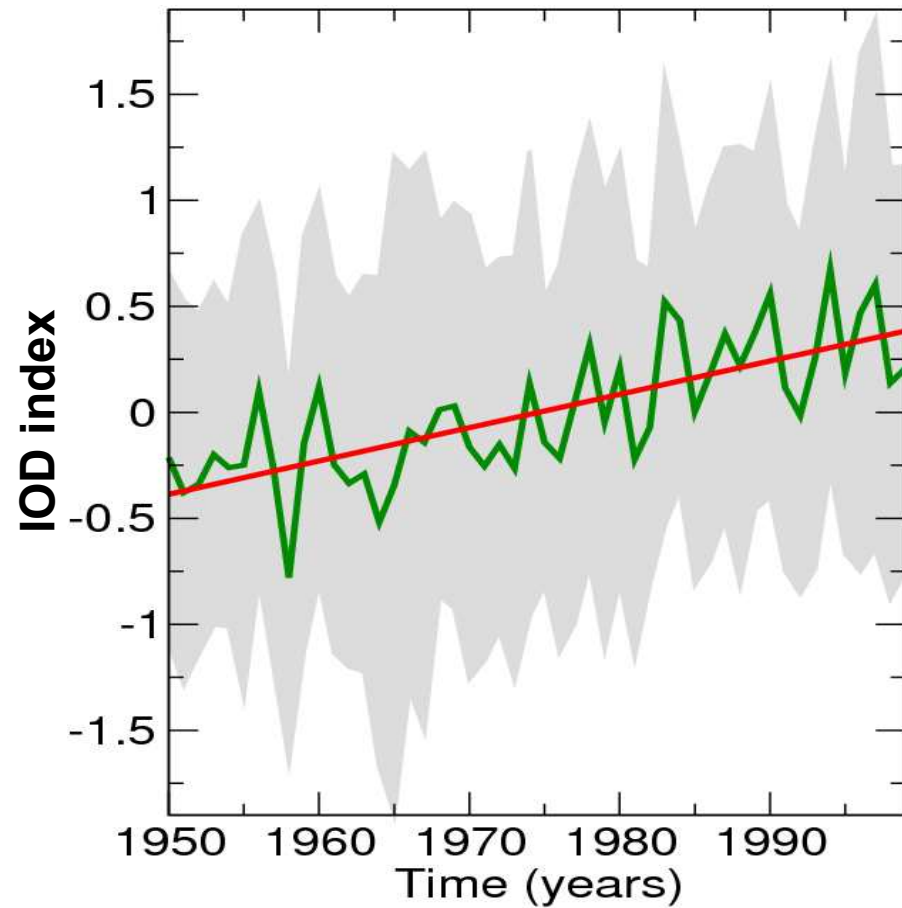
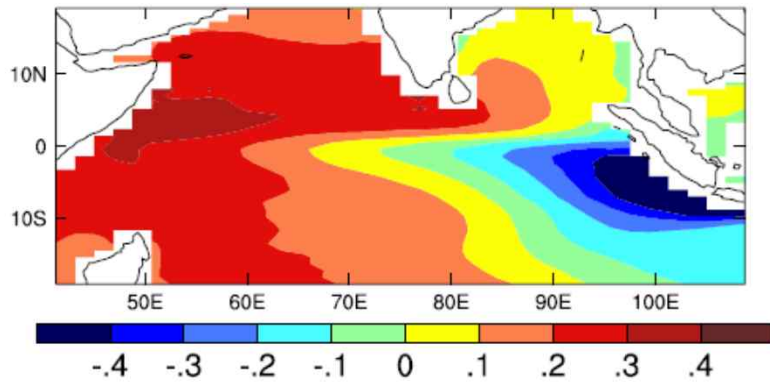
# Drought: a great pre-condition for bushfires

- **Black Saturday (7 February 2009)**
  - Temp = 46.4°C
  - Relative Humidity ~10%
  - Total death: 170+
  - ~2000 houses burnt



# Trend in the IOD: 19 climate models

- Some of the IOD trend is attributable to climate change



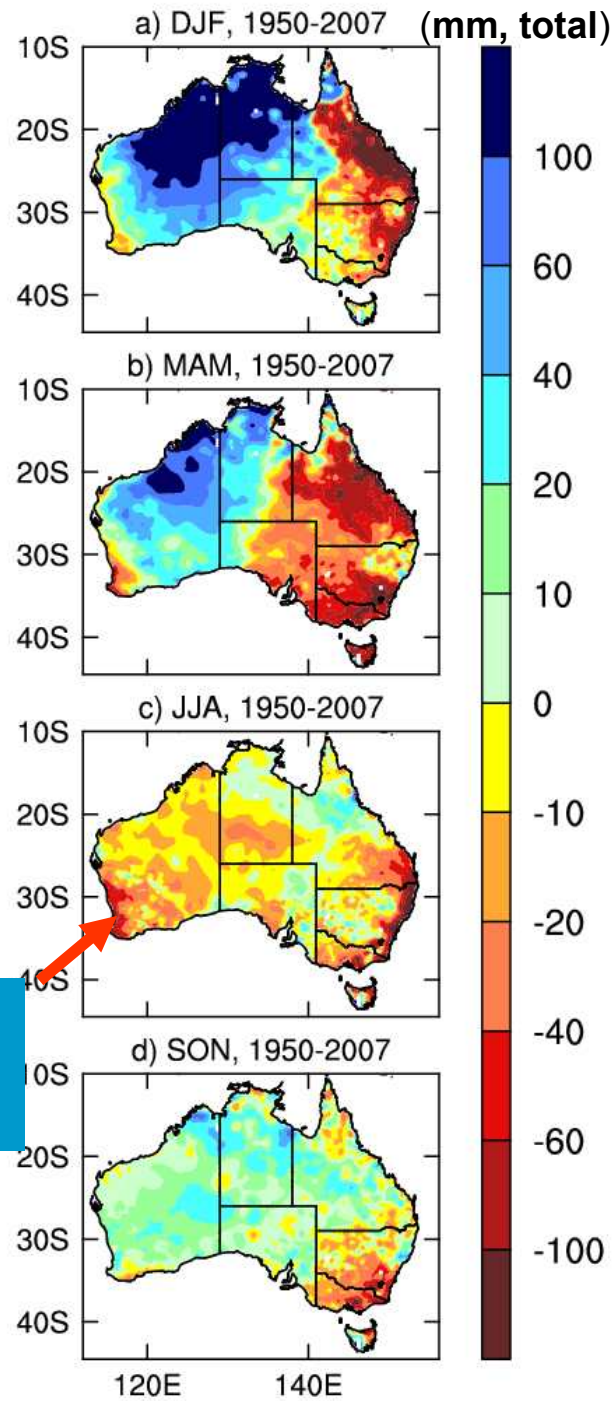
Cai et al. 2009, GRL

# Global warming and IOD frequencies from 19 IPCC-class climate models: 1951-2000

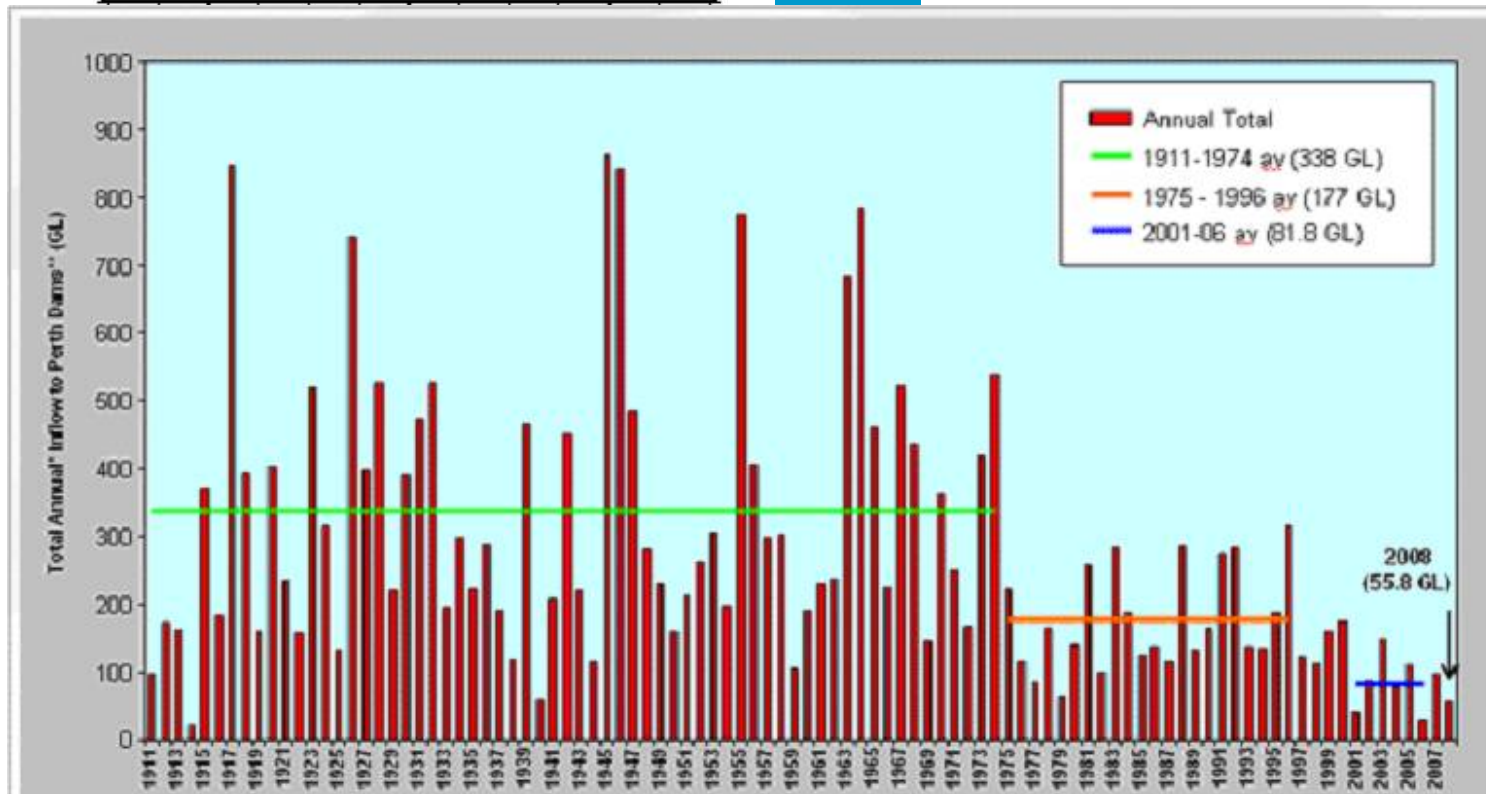
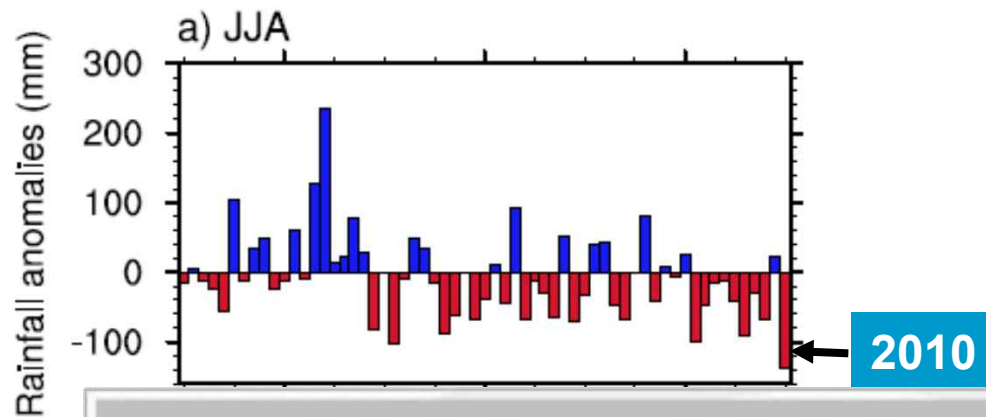
|                               | Number of positive IOD (pIOD) |                        |
|-------------------------------|-------------------------------|------------------------|
| <b>With Climate Change</b>    | <b>224</b>                    |                        |
| <b>Without Climate Change</b> | <b>192</b>                    |                        |
|                               | Two consecutive pIOD          | Three consecutive pIOD |
| <b>With Climate Change</b>    | <b>42</b>                     | <b>8</b>               |
| <b>Without Climate Change</b> | <b>32</b>                     | <b>2</b>               |

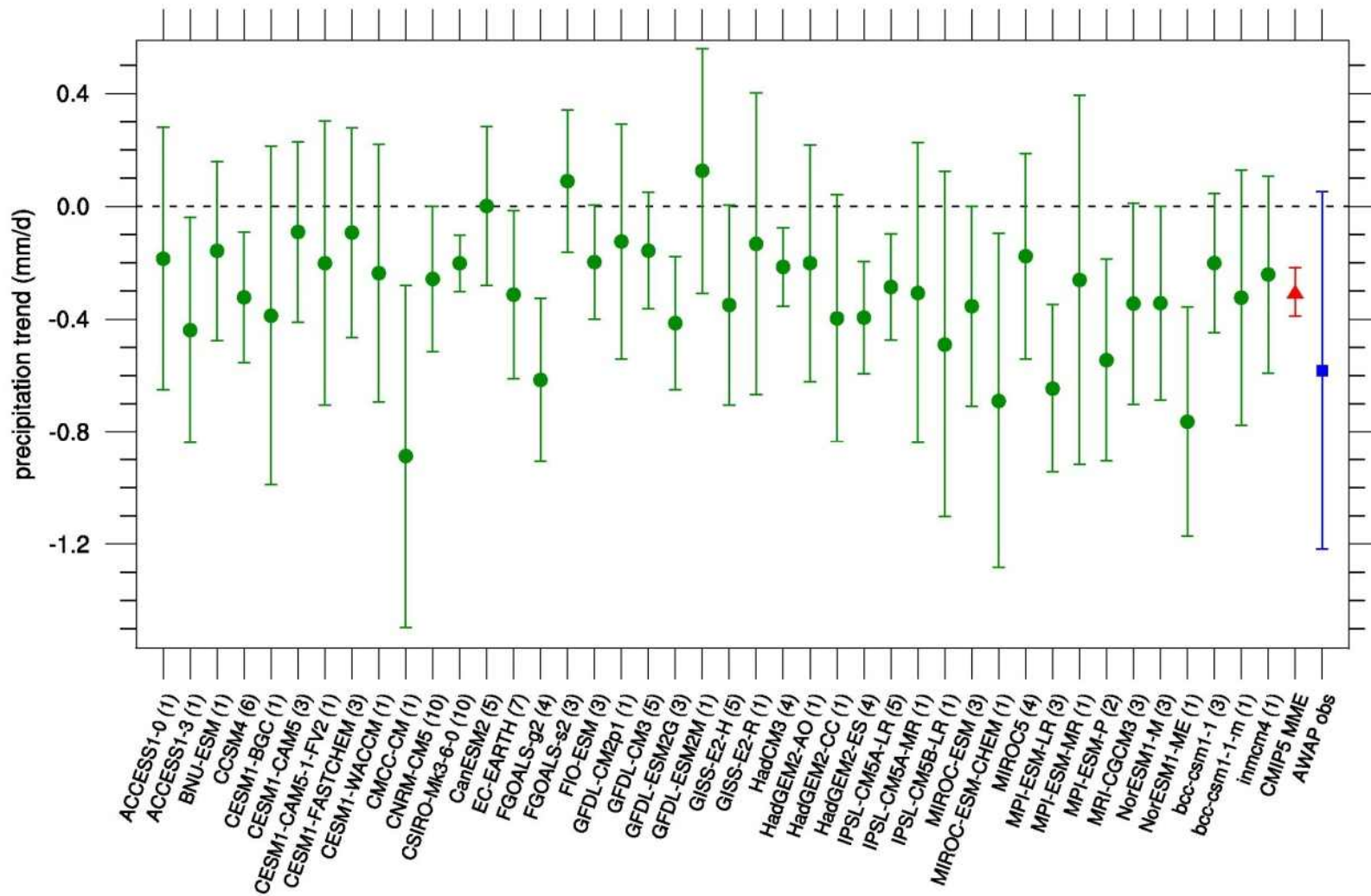
Climate change is increasing the frequency of positive IOD events.

**Positive SAM trend**

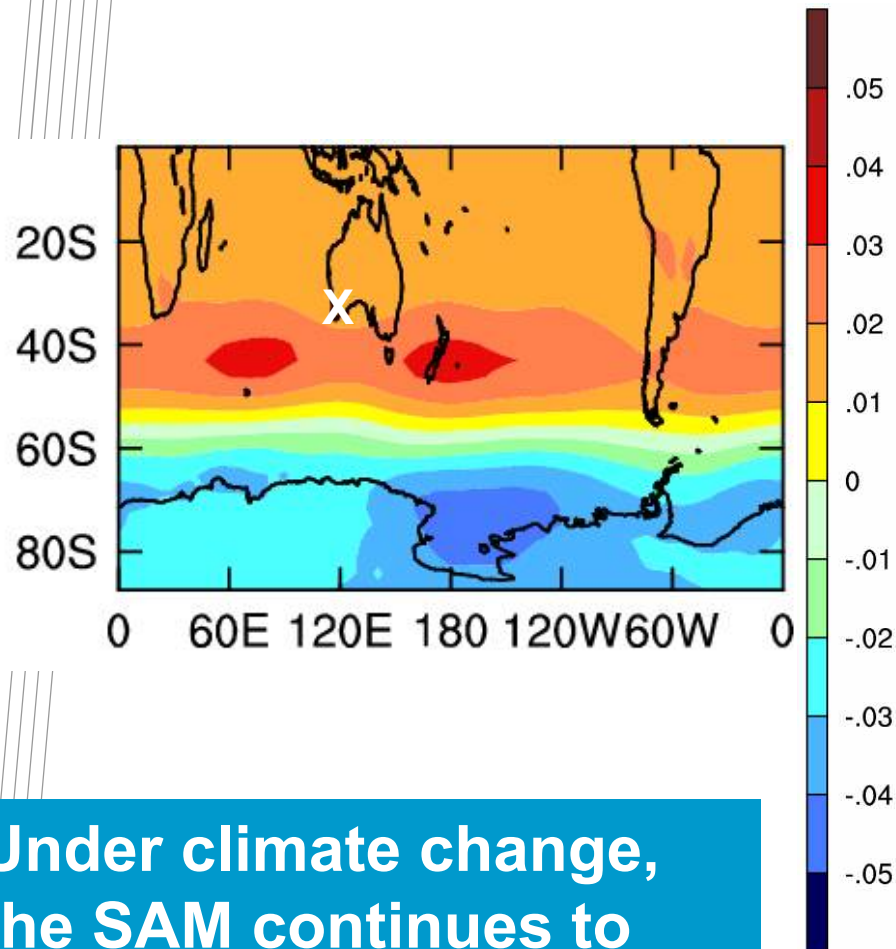


# The SWWA drought continues and there is a significant reduction in inflows to dams

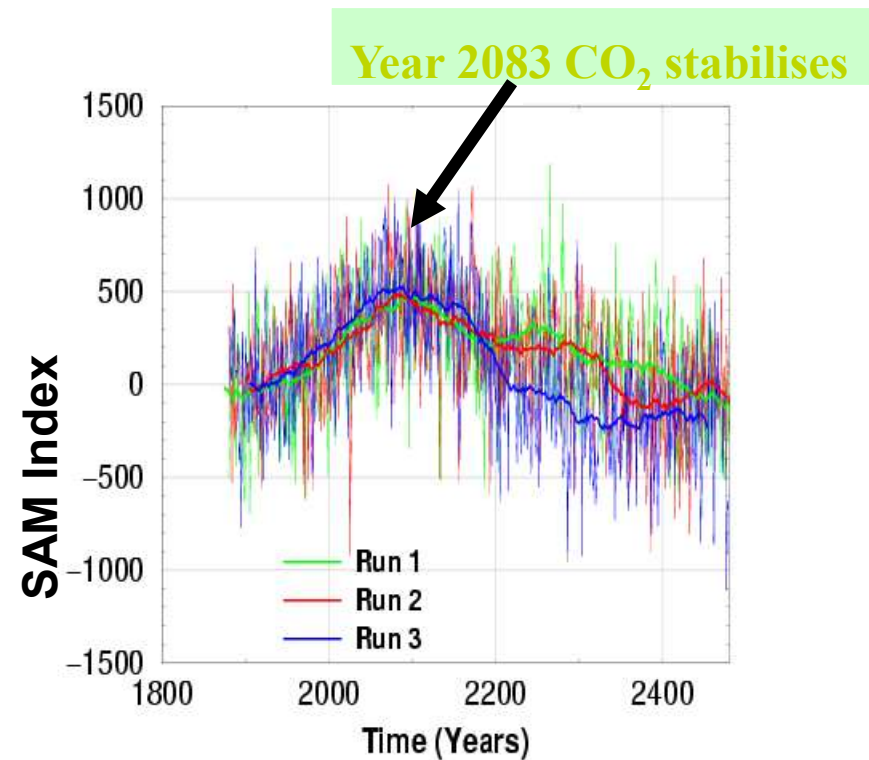




# Greenhouse-induced upward trends of the SAM



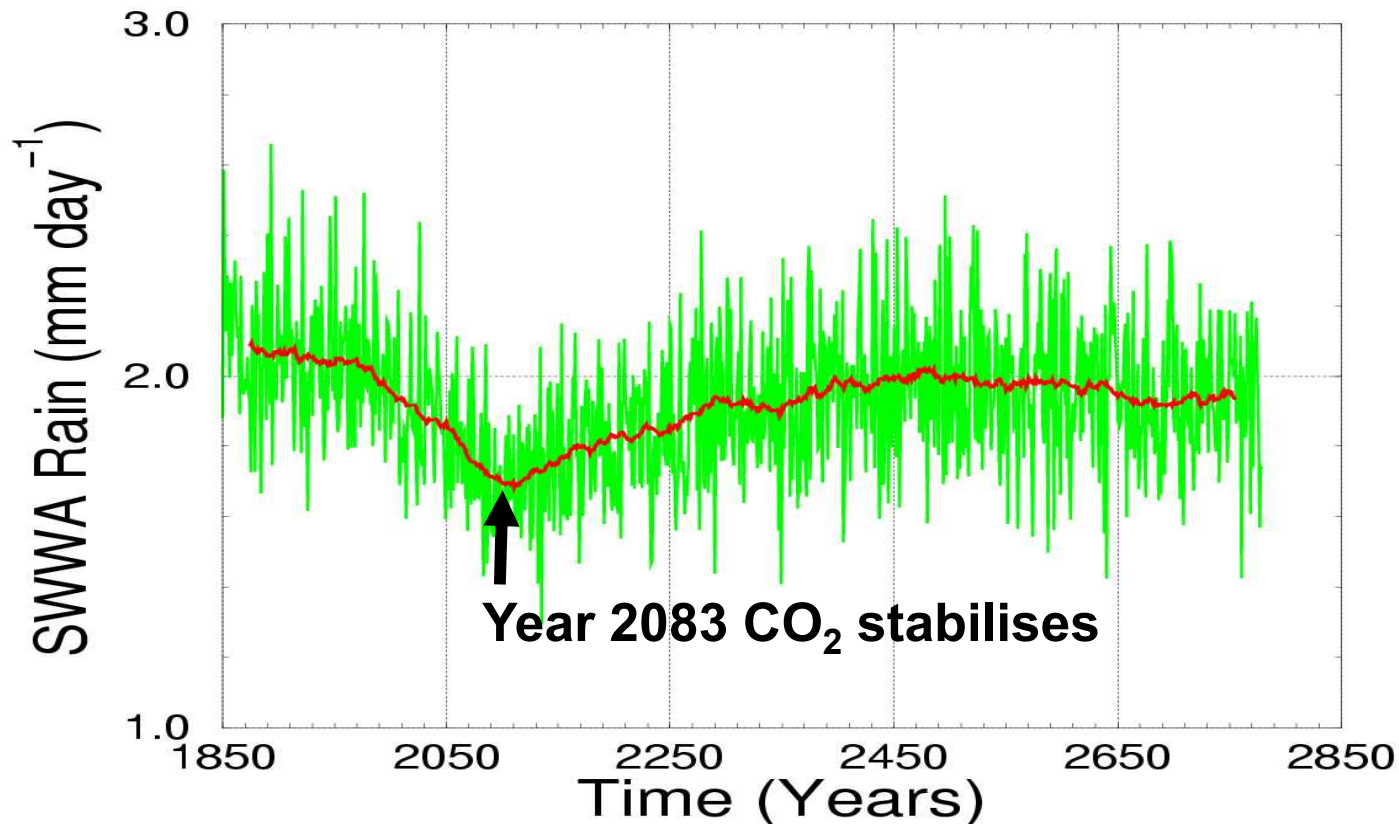
**Under climate change, the SAM continues to trend up**



**Only after CO<sub>2</sub> is stabilised (yr 2083 in the model), does the SAM reverse its trend.**

# CO<sub>2</sub> & SWWA rainfall

Cai, Whetton & Karoly, 2003



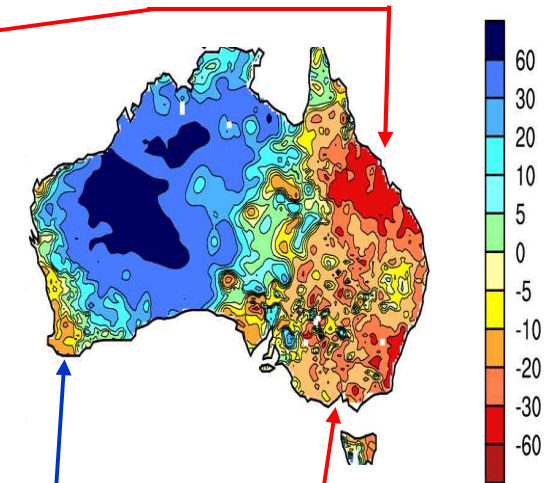
**Rainfall decreases while CO<sub>2</sub> increases, but recovers in 500 years after CO<sub>2</sub> stabilises.**

# We are telling three stories

Story 1: The IPO/PDO influences the impact of ENSO on eastern Australia. When the PDO is positive (since 1980), La Nina no longer brings rainfall to east Australia, leading to a severe drought.

Story 2: The Indian Ocean Dipole is trending up, contributed by climate change, and is contributing to droughts, rising temperature, and severe bushfires over Southeast Australia.

Story 3: The SAM trends up (with increasing pressure over Australia) while CO<sub>2</sub> is increasing but reverses trend once CO<sub>2</sub> stabilises. In response, SWWA rainfall behaves similarly.



# Recent papers

- Cai, W, P. van Rensch, T. Cowan, A. Sullivan (2010), Asymmetry in ENSO Teleconnection with Regional Rainfall, Its Multidecadal Variability, and Impact. *J. Climate*, 23, 4944–4955. doi: 10.1175/2010JCLI3501.1
- Cai, W., A. Pan, D. Roemmich, T. Cowan, and X. Guo (2009), Argo profiles a rare occurrence of three consecutive positive Indian Ocean Dipole events, 2006–2008, *Geophys. Res. Lett.*, 36, L08701, doi:10.1029/2008GL037038.
- Cai, W., T. Cowan, and A. Sullivan (2009), Recent unprecedented skewness towards positive Indian Ocean Dipole occurrences and its impact on Australian rainfall, *Geophys. Res. Lett.*, 36, L11705, doi:10.1029/2009GL037604.
- Cai, W., A. Sullivan, and T. Cowan (2009), How rare are the 2006–2008 positive Indian Ocean Dipole events? An IPCC AR4 climate model perspective, *Geophys. Res. Lett.*, 36, L08702, doi:10.1029/2009GL037982.
- Cai, W., T. Cowan, and M. Raupach (2009), Positive Indian Ocean dipole events precondition southeast Australia bushfires, *Geophys. Res. Lett.*, 36, L19710, doi:10.1029/2009GL039902.
- Cai, W., T. Cowan and A. Sullivan (2009): Climate change contributes to more frequent consecutive positive Indian Ocean Dipole events, *Geophys. Res. Lett.*,
- Cai, W., and T. Cowan (2006): SAM and regional rainfall in IPCC AR4 models: Can anthropogenic forcing account for southwest Western Australian winter rainfall reduction?, *Geophys. Res. Lett.*, 33, L24708, doi:10.1029/2006GL028037.

End