THE UNIVERSITY OF NEW SOUTH WALES
SYDNEY • AUSTRALIA

Atmosphere

Impacts of Indo-Pacific Variability on Rainfall and Drought across the Australasian Region

Caroline Ummenhofer

Land

Collaborators:

Matthew England, Alex Sen Gupta, Andrea Taschetto (CCRC)
Peter McIntosh, Gary Meyers, Mike Pook, James Risbey (CSIRO)

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Ocean

General outline

- Background & motivation
- West Australian rainfall
    - Experimental design of model simulations
    - Rainfall changes and mechanisms
    - Implications for forecasting
- E African rainfall
    - Relative importance of individual Indian Ocean SST ‘poles‘
- Prolonged SE Australian droughts
    - Importance of the Indian Ocean
- Modulation of ENSO-Indian monsoon relationship by Indian Ocean variability
- Summary

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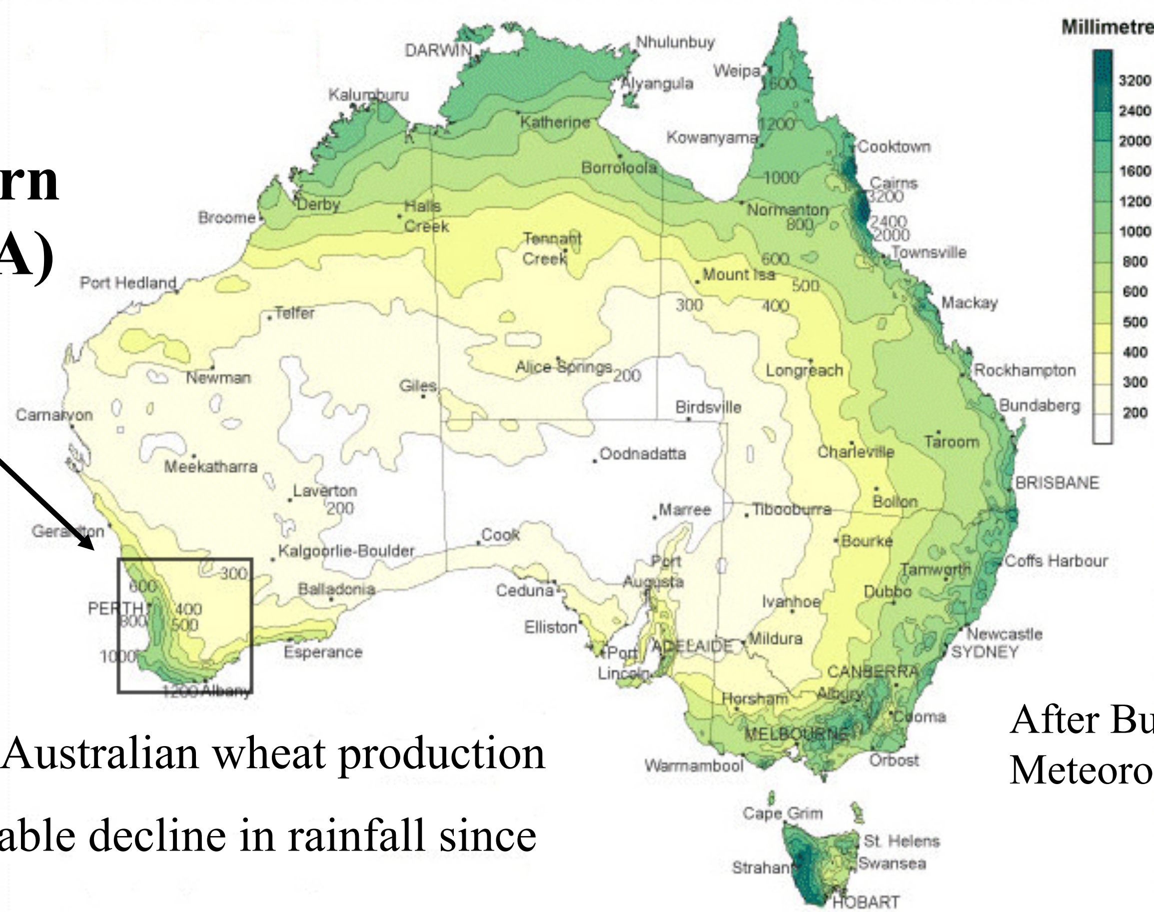
Australian annual precipitation

Southwest Western Australia (SWWA)



After Bureau of Meteorology

- Characterized by Mediterranean climate with wet winters/dry summers

- Accounts for ~40% of Australian wheat production

- Experiencing considerable decline in rainfall since 1970 's

→ **Better understanding of interannual variability vital under these exacerbated conditions**

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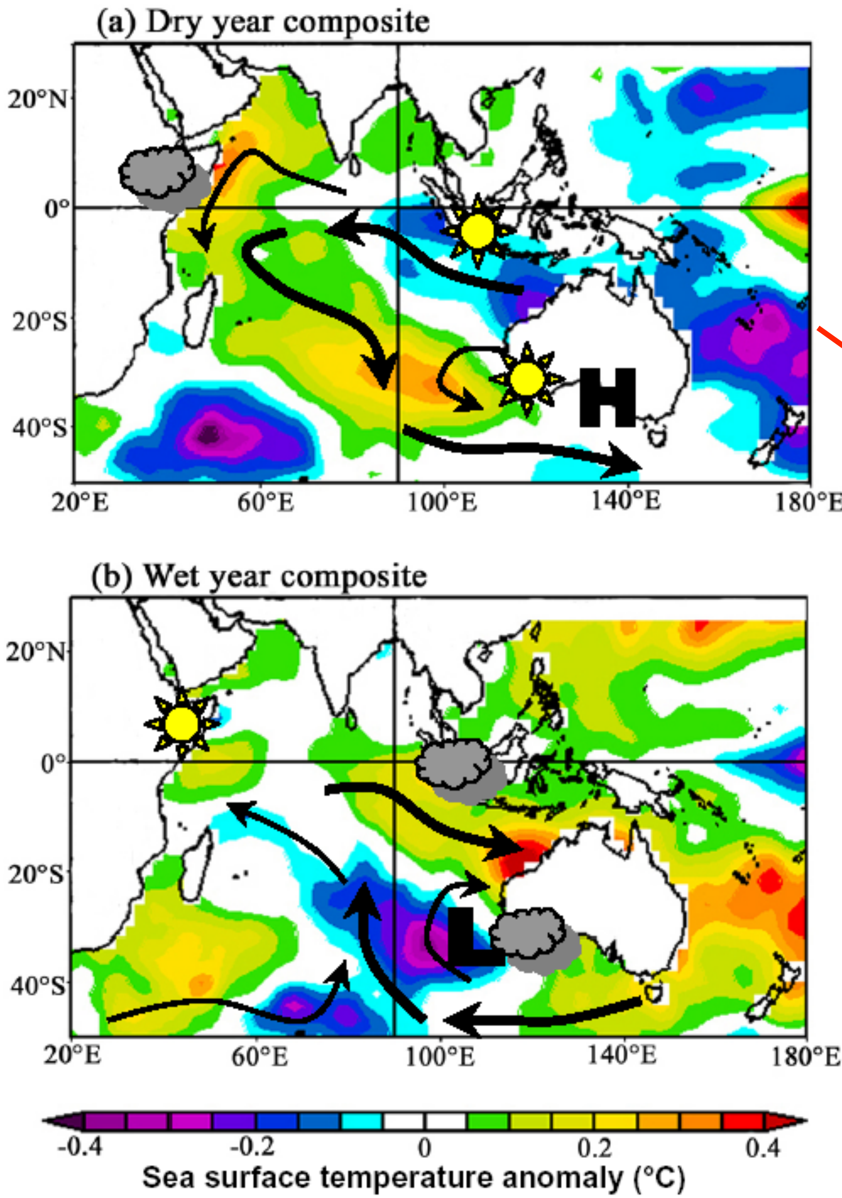

England *et al.* (2006) investigated **extreme rainfall years in SWWA** in observations and multi-century coupled climate model simulation:

DRY years
- Characteristic dipole pattern in Indian Ocean SST anomalies

- Acceleration of anticyclonic basin-wide wind field

- Anomalous offshore moisture advection over SWWA

Situation reversed during **WET** years

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Experimental design

Based on **monthly observed SST anomalies** during extreme rainfall years in SWWA from England *et al.* (2006)

↓

Superimposed on SST climatology

↓

60 ensemble members of 1-year simulations for **PDRY** and **PWET** cases

- **AGCM experiments** with NCAR ‘s CAM3 run in T42 standard configuration, **forced with SST**

- 80-year CONTROL simulation with SST climatology;
Perturbation cases for dry years (**PDRY**) and wet years (**PWET**)

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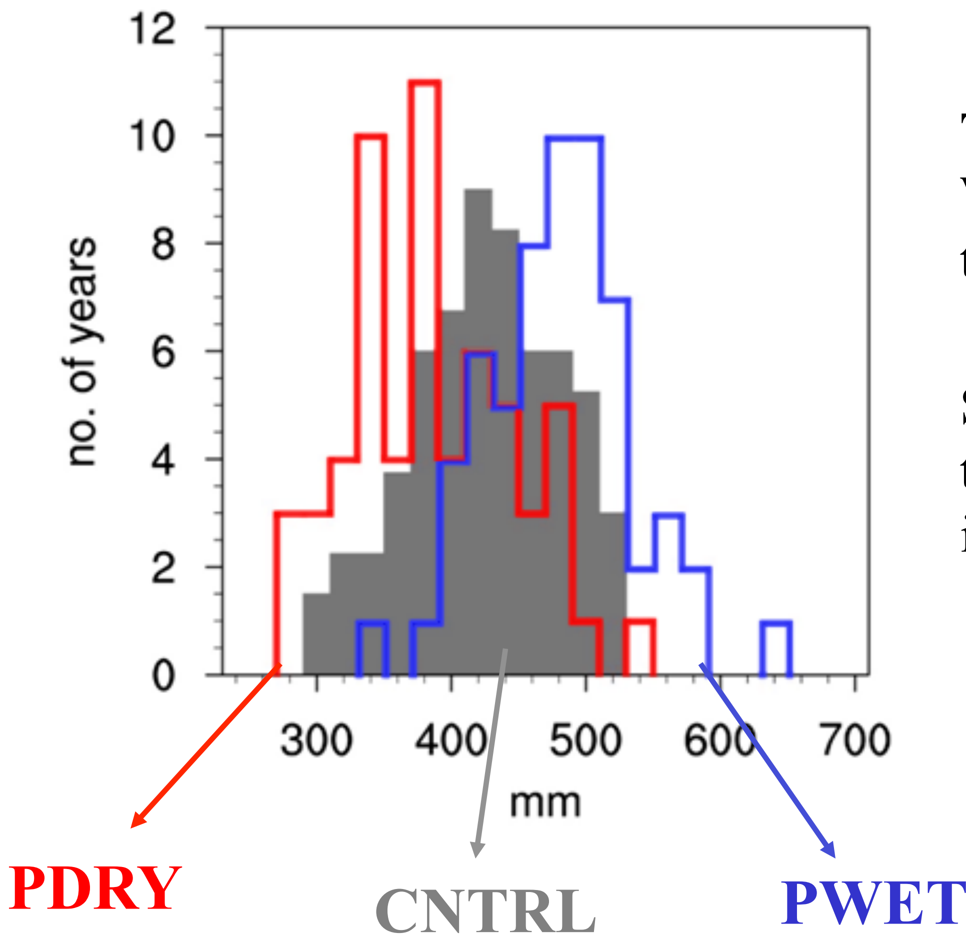
Rainfall changes over W Australia



Total annual precipitation over Western Australia (excluding tropical north)

Shift of entire distribution, towards the lower (upper) end in PDRY (PWET)

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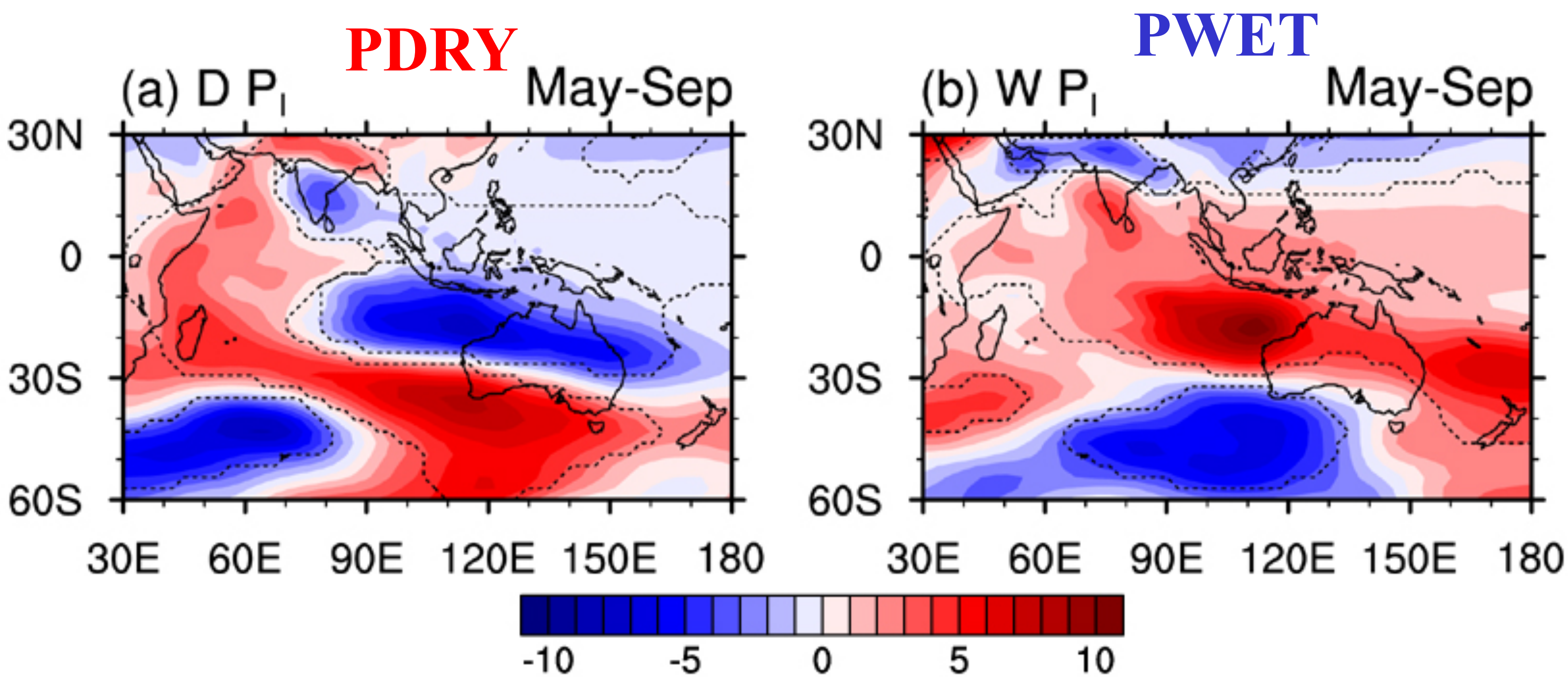
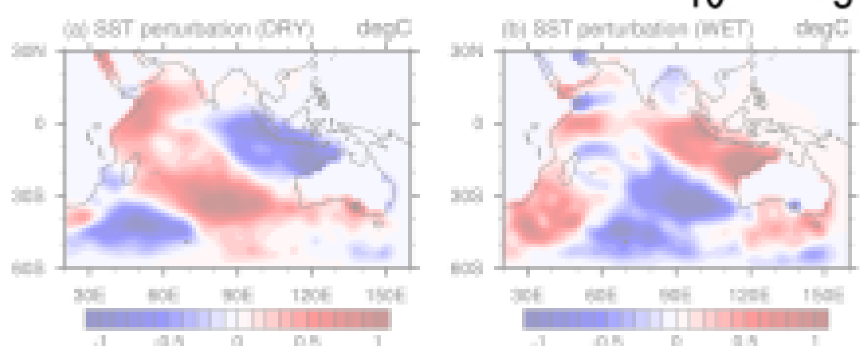
Thickness anomalies (1000-500hPa) – MJJAS





- negative/positive thickness anomalies across Indian Ocean reflect sign and position of SST poles

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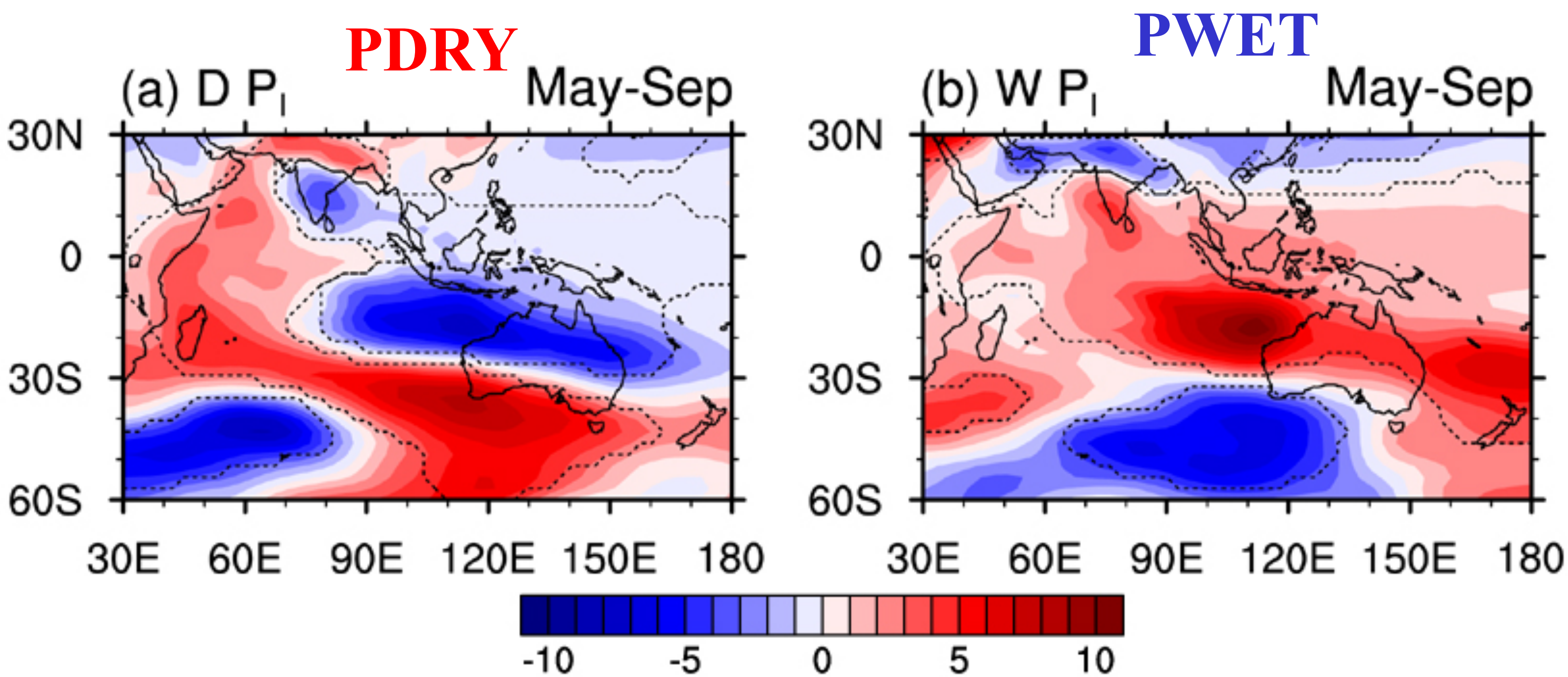
Thickness anomalies – cont ‘d



- Reduced (increased) meridional thickness gradient leads to easterly (westerly) anomaly in thermal wind over southern regions of Australia

- Southward (northward) deflection of strengthening southwesterly jet to the south of Australia, along with rain-bearing fronts

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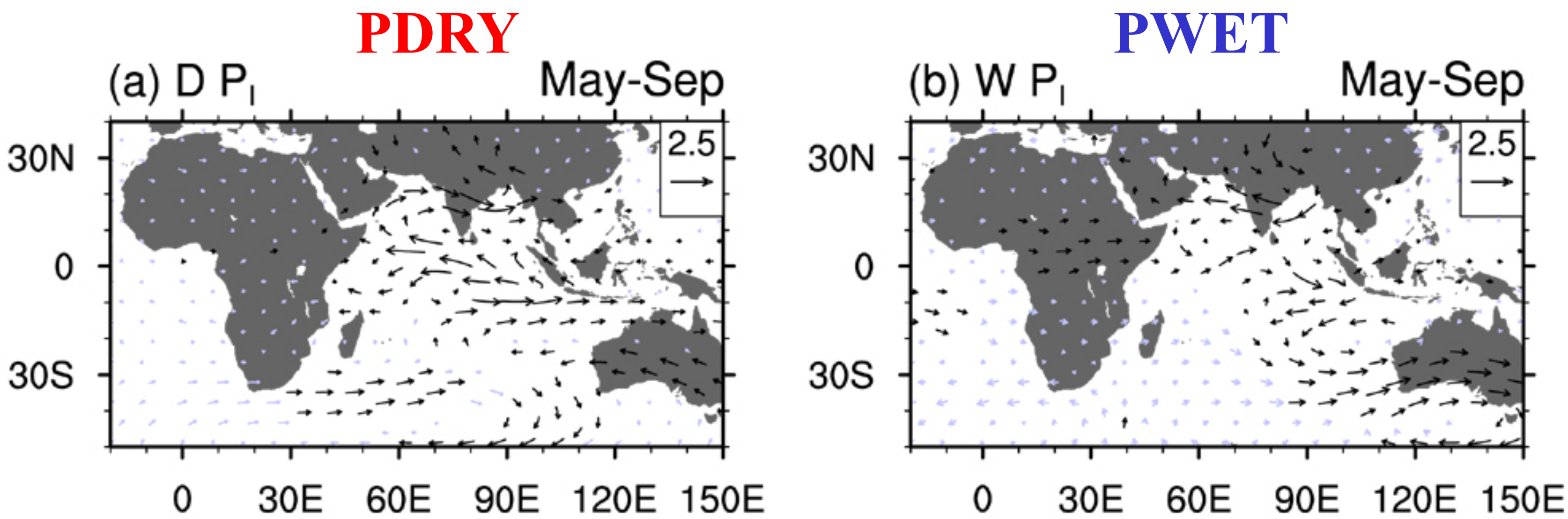
Wind anomalies (500hPa) - MJJAS



- Weakening (strengthening) of anticyclonic wind field over the Indian Ocean during PDRY (PWET)

- Weakened (strengthened) onshore wind over southern regions of Australia during PDRY (PWET)

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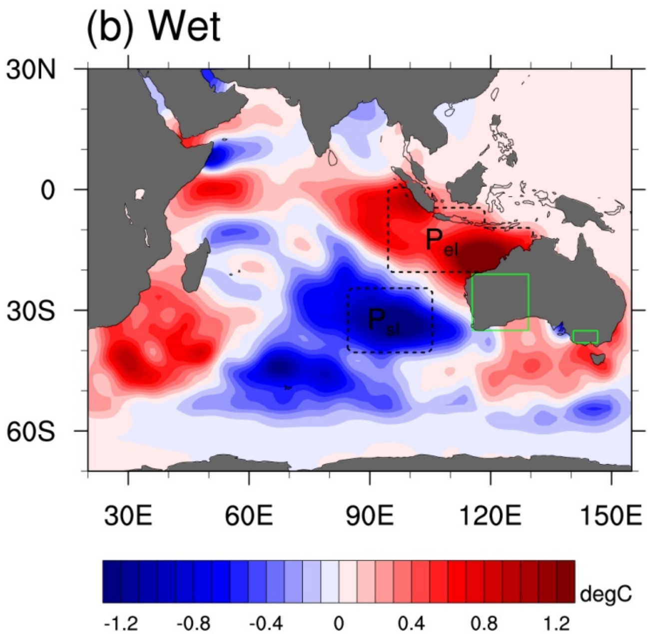
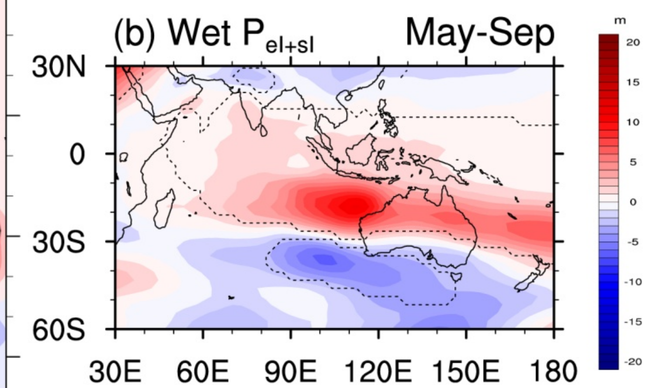
Relative importance of SST poles

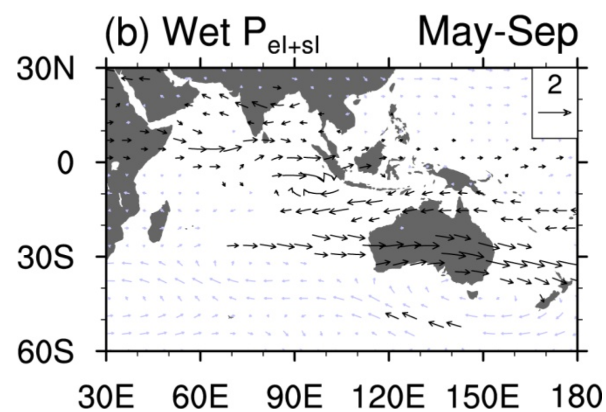
SSTA (May-Sep)



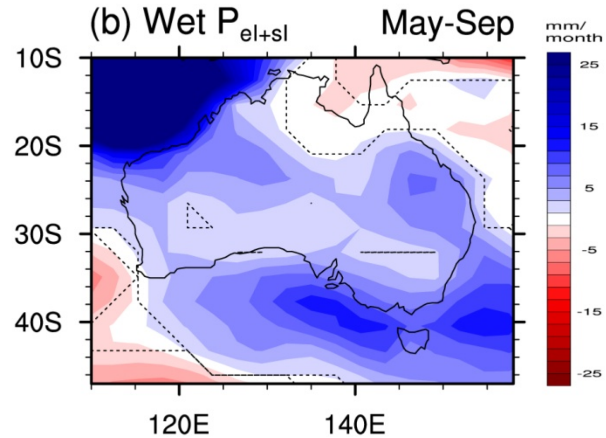
Thickness anomalies
(1000-500hPa)



Wind anomalies
(500hPa)



Rainfall anomalies



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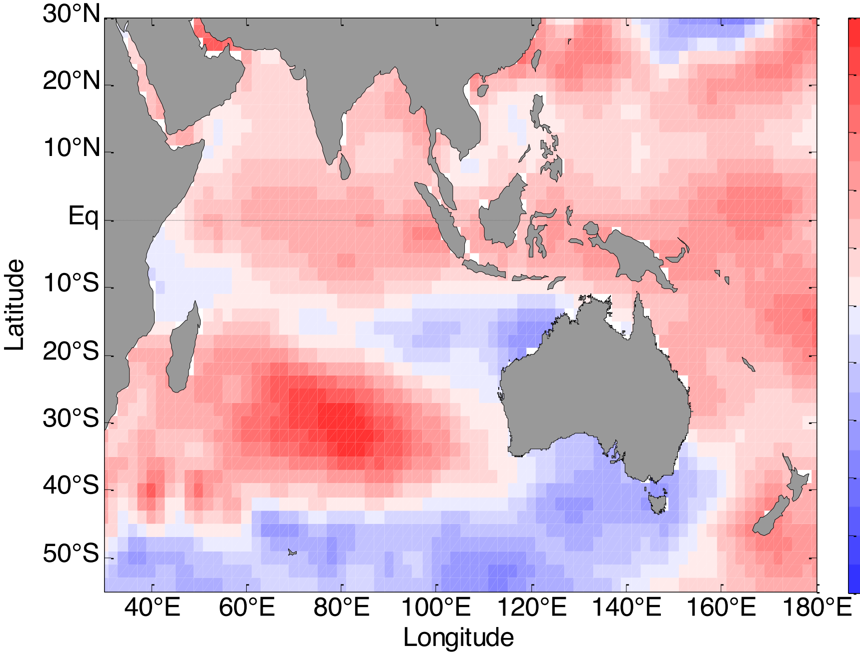
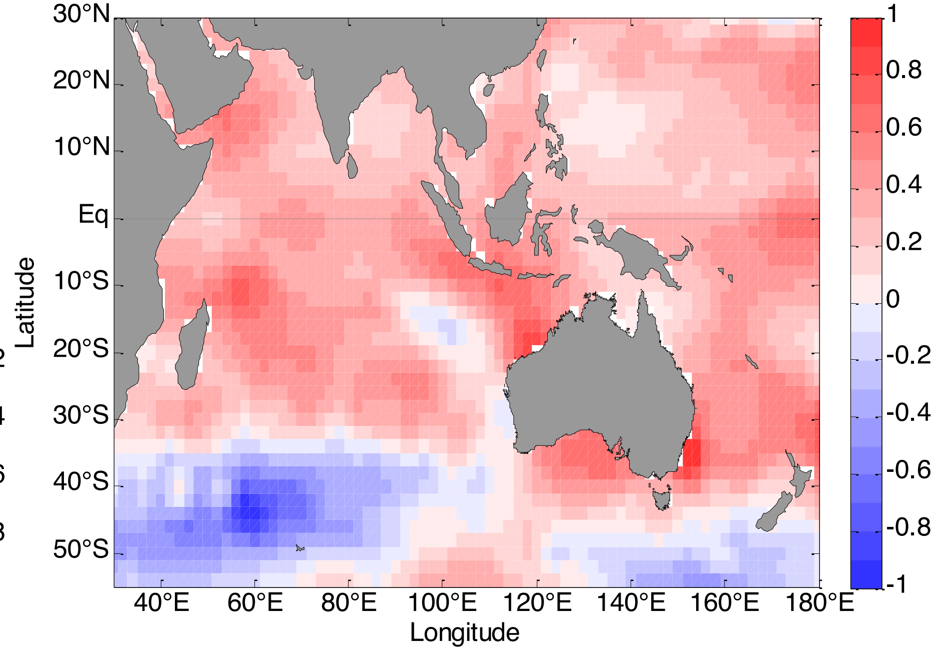
Implications for seasonal forecasting

2006 SST anomalies April-July 2005





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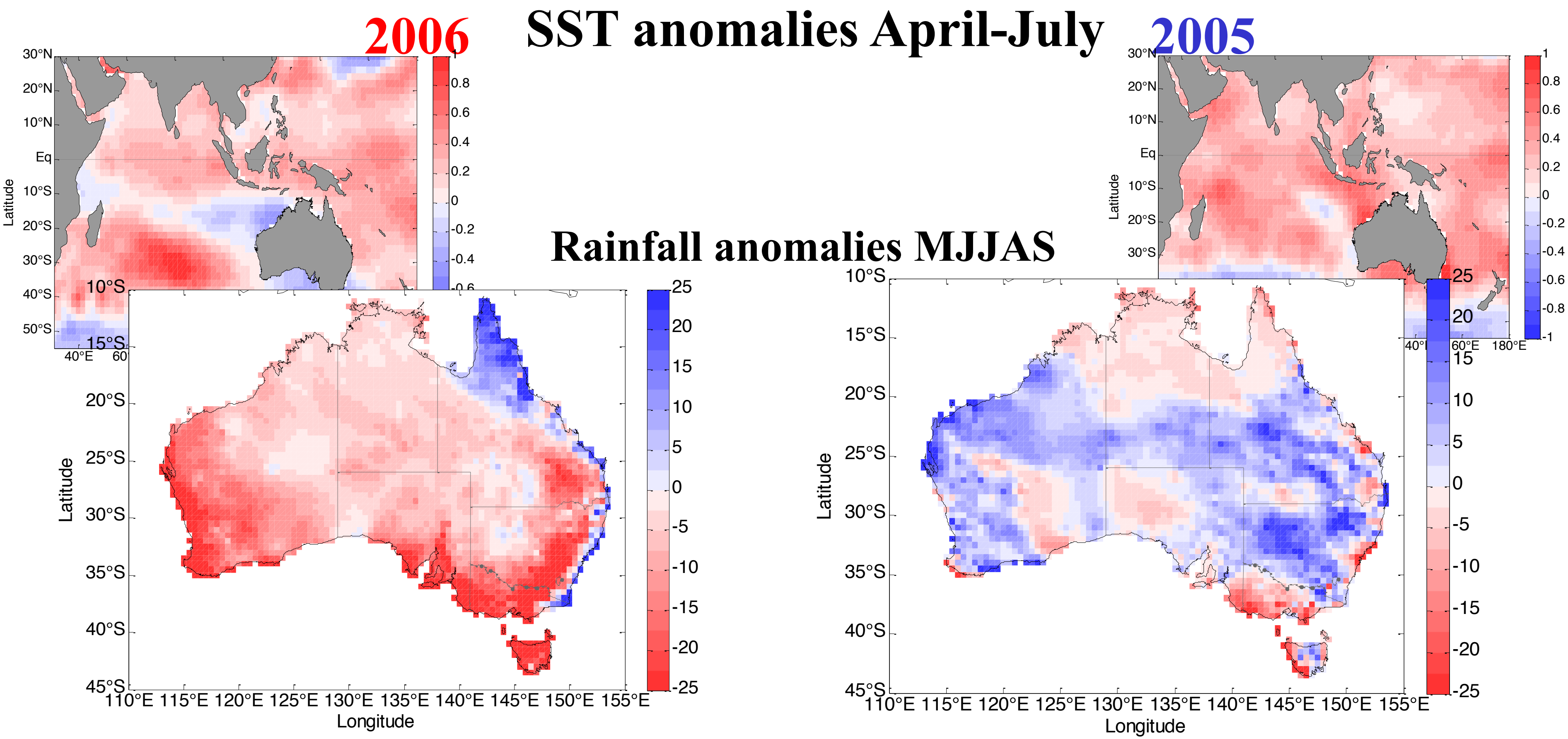
Implications for seasonal forecasting



- Characteristic SST pattern in Indian Ocean worked as indicator for rainfall in western regions of Australia (2005-2006)

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Implications for seasonal forecasting

Department of Agriculture and Food (WA) uses **meridional SST gradient across eastern Indian Ocean** in growing season outlook for farmers:

WA Climate Indicators Summary

Climate Indicator	**Meaning**	**Current status**
1. ENSO state (global – Indo-Pacific)	Pressure, SST - picked by ESS	Neutral to weak El Niño (**-**)
2. Barometric Pressure over Australia	Strongly relates to rain – stronger high pressures relate to dry conditions	Australian Pressure – high and on a rising trend (**X**)
3. SST gradient in Indian Ocean	How warm is ocean north/SW of WA	SST cool north of Australia, warm southwest of WA (reduced SST gradient) (**X**)
4. Cloudband activity	Important in NAR, CAR	No NW cloud-bands over the wheat-belt yet, few cut-off lows (**X**)
5. Frontal activity	Important in SAR	Tracking south, weaker than normal (**X**)

(X) = negative trend, (-) = no trend indicated, (√) = positive trend

From Growing Season Outlook (July 2008)

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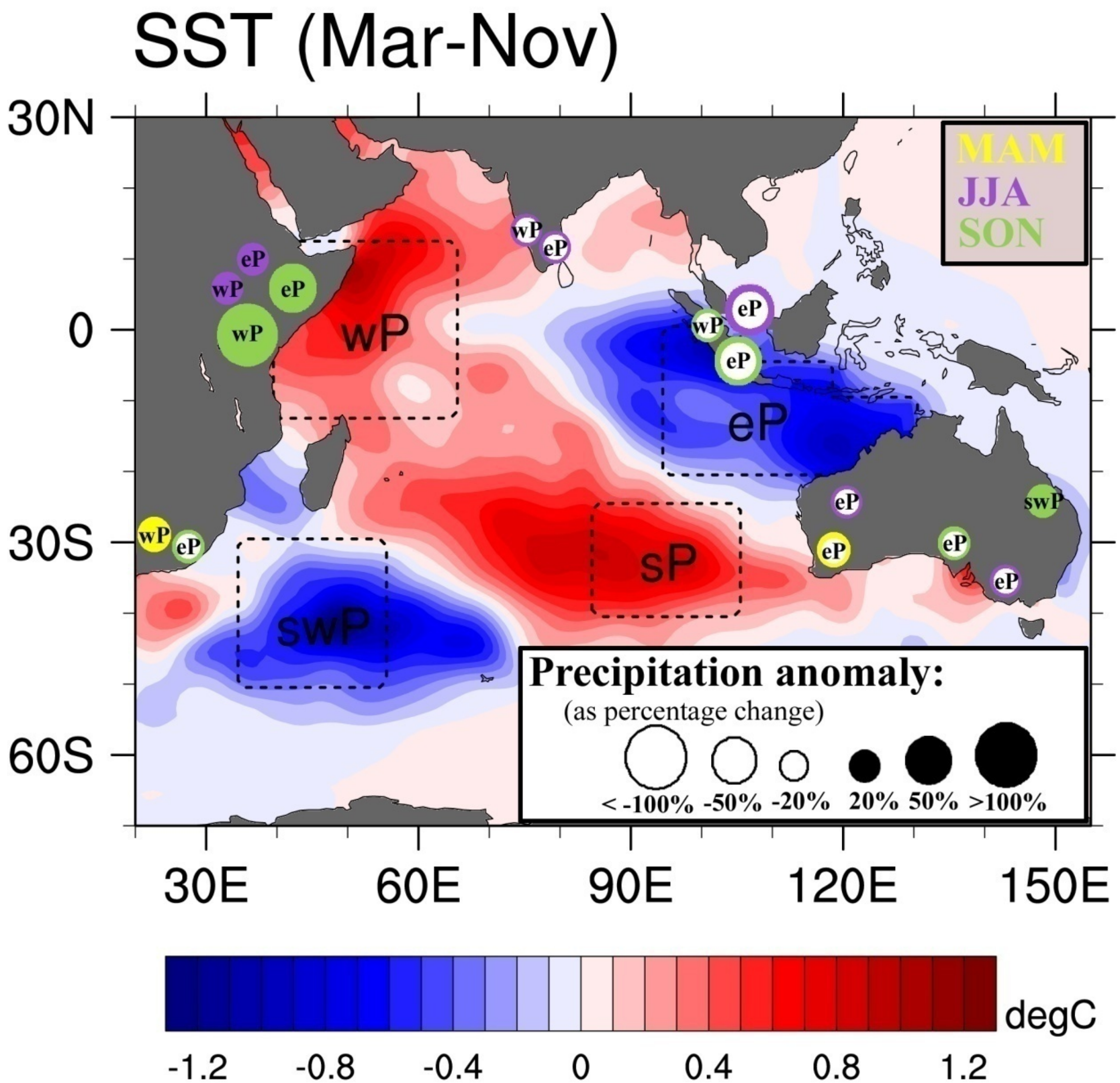
Rainfall changes associated with SST anomalies – for separate poles



Schematic of the impact of Indian Ocean SST anomalies on precipitation in Indian Ocean-rim countries in AGCM simulations during different seasons.

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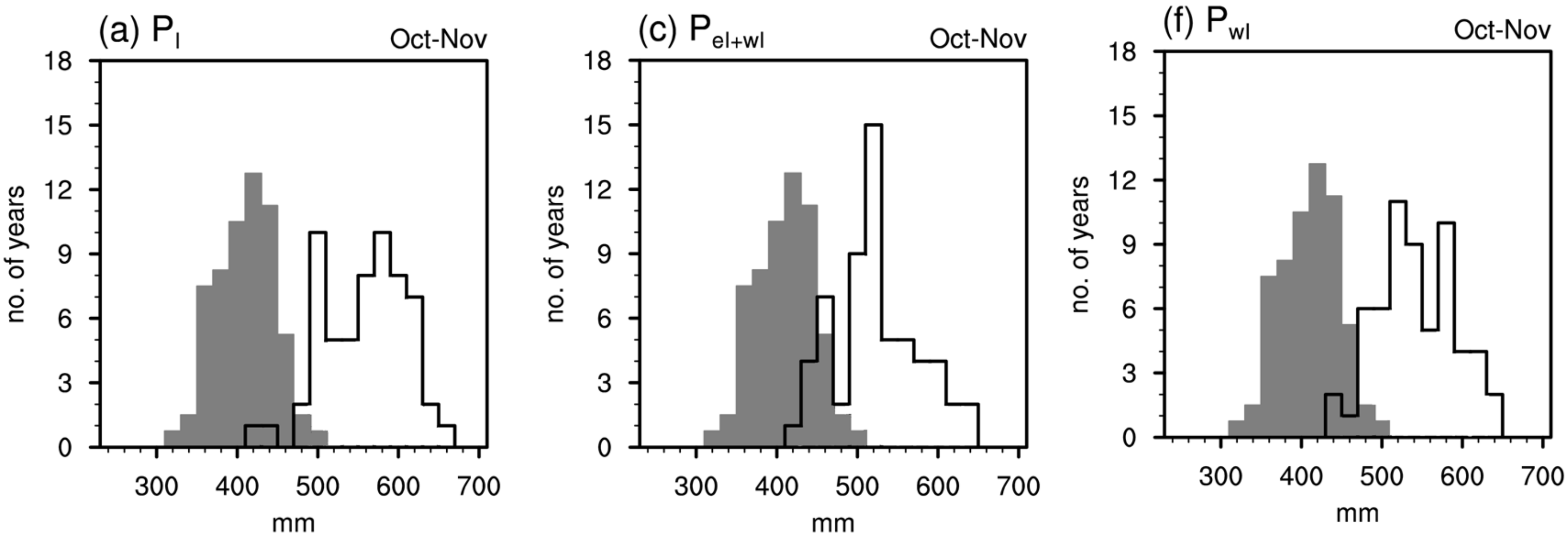
Rainfall anomalies associated with poles

SSTA for **entire Indian Ocean**

SSTA for **eastern & western poles**

SSTA for **western pole**



- Enhanced East African "short rains" mainly due to warm SST anomalies in western pole

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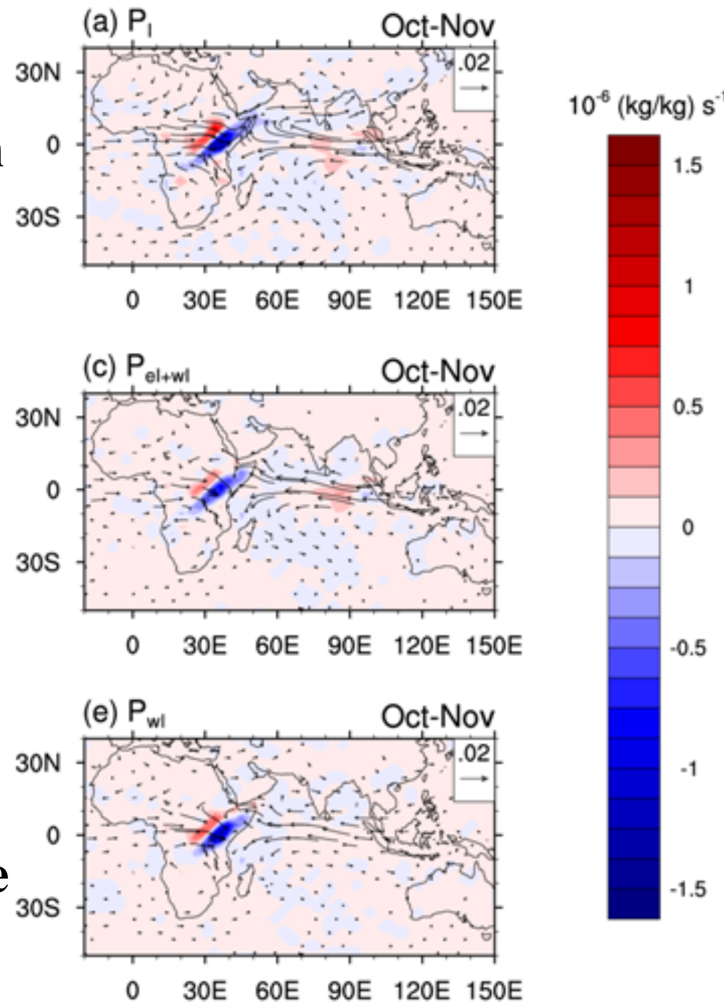
Anomalies in moisture flux associated with poles of SST

SSTA for **entire Indian Ocean**

SSTA for **eastern & western poles**

SSTA for **western pole**



Enhanced East African rainfall due mainly to warm western pole in eq. Indian Ocean, causing **moisture convergence**

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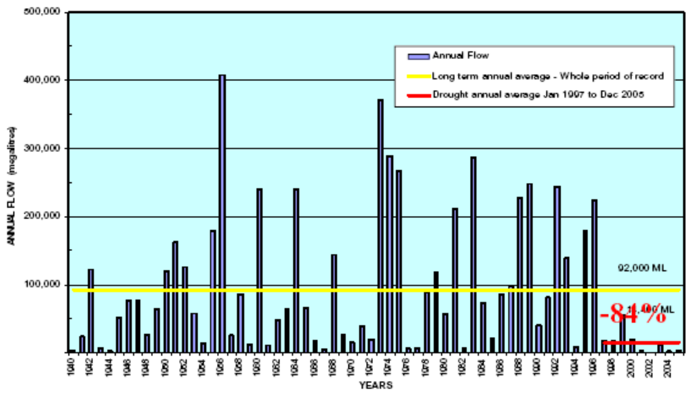
SE Australia

- Over last 10 years, **total inflows** into the River Murray system **42% below long-term average**
- In western Victoria total inflows a staggering 60-90% below average

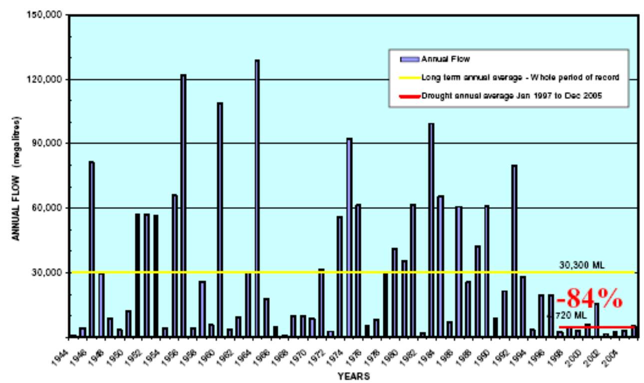
→Enormous consequences as Murray Darling basin generates ~40% of Australia's agricultural production, with ~70% of the country's irrigation occurring in the region

→ Federal Government drought assistance exceeding A$2.2 billion (2002-2008)

North-West: Avoca River at Coonooer
1940-2005 & 1997-2005



South-West: Hopkins River at Wickliffe
1943-2005 & 1997-2005



From SEACI

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Classification of IOD/ENSO years

	Negative IOD	Neutral	Positive IOD
El Niño	1930	1877, 1888, 1899, 1905, 1911, 1914, 1918, 1925, 1940, 1941, 1965, 1972, 1986, 1987	1896, 1902, 1957, 1963, 1982, 1991, 1997
Neutral	1915, 1958, 1968, 1974, 1980, 1985, 1989, 1992	1880, 1881, 1882, 1883, 1884, 1895, 1898, 1900, 1901, 1904, 1907, 1908, 1912, 1920, 1921, 1927, 1929, 1931, 1932, 1934, 1936, 1937, 1939, 1943, 1947, 1948, 1951, 1952, 1953, 1959, 1960, 1962, 1966, 1967, 1969, 1971, 1976, 1977, 1979, 1983, 1990, 1993, 1995, 2001, 2002, 2003, 2005, 2006	1885, 1887, 1891, 1894, 1913, 1919, 1923, 1926, 1935, 1944, 1945, 1946, 1961, 1994, 2004
La Niña	1906, 1909, 1916, 1917, 1933, 1942, 1975	1878, 1879, 1886, 1889, 1890, 1892, 1893, 1897, 1903, 1910, 1922, 1924, 1928, 1938, 1949, 1950, 1954, 1955, 1956, 1964, 1970, 1973, 1978, 1981, 1984, 1988, 1996, 1998, 2000	1999

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Classification based on Meyers et al. (2007); Updated in Ummenhofer et al. (2009)

Rainfall anomalies in the ENSO/IOD categories

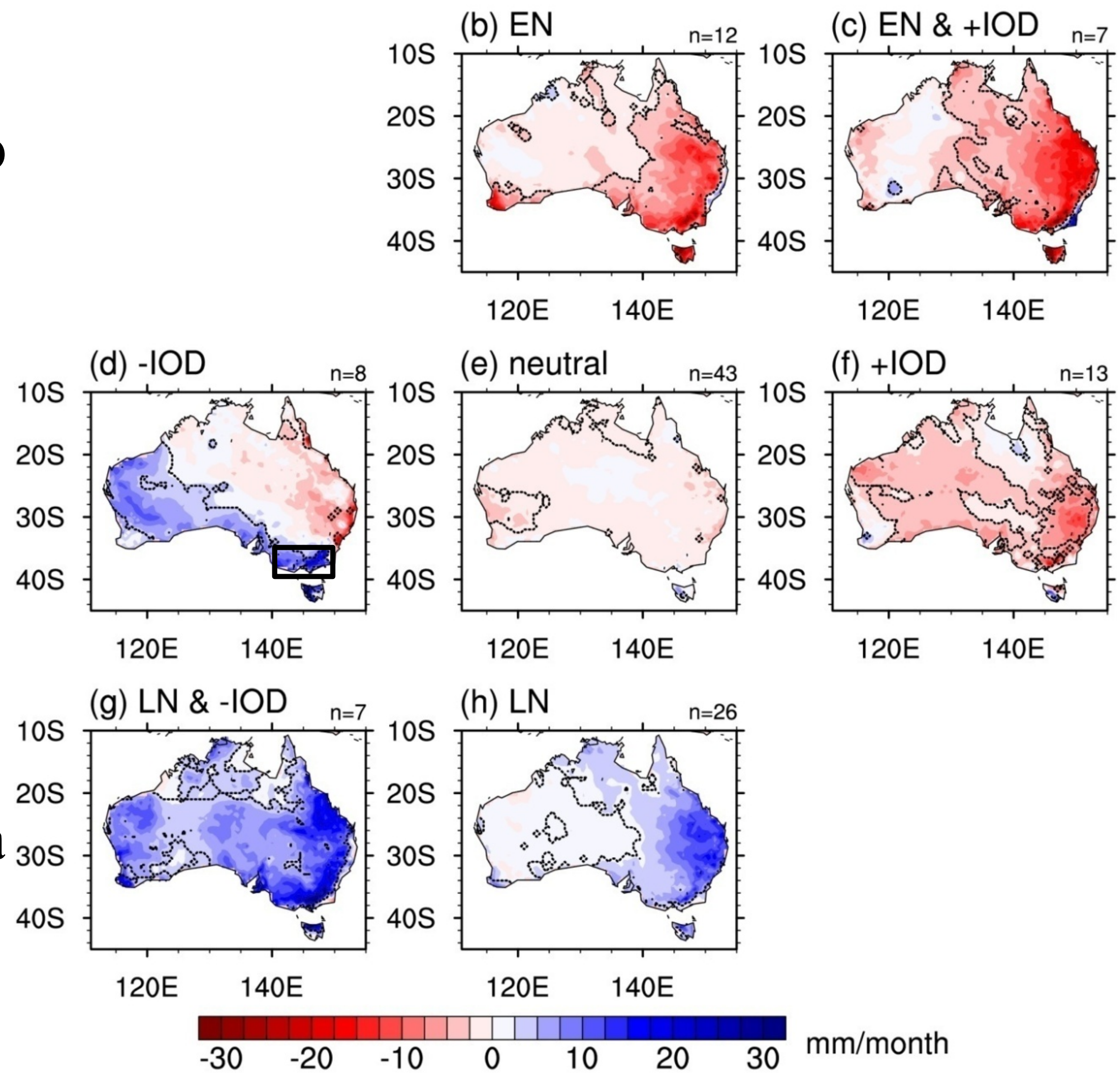
-IOD **+IOD**

El Niño

Rainfall anomalies during **Jun-Oct**

Classification based on Meyers et al. (2007); Updated in Ummenhofer et al. (2009)

La Niña



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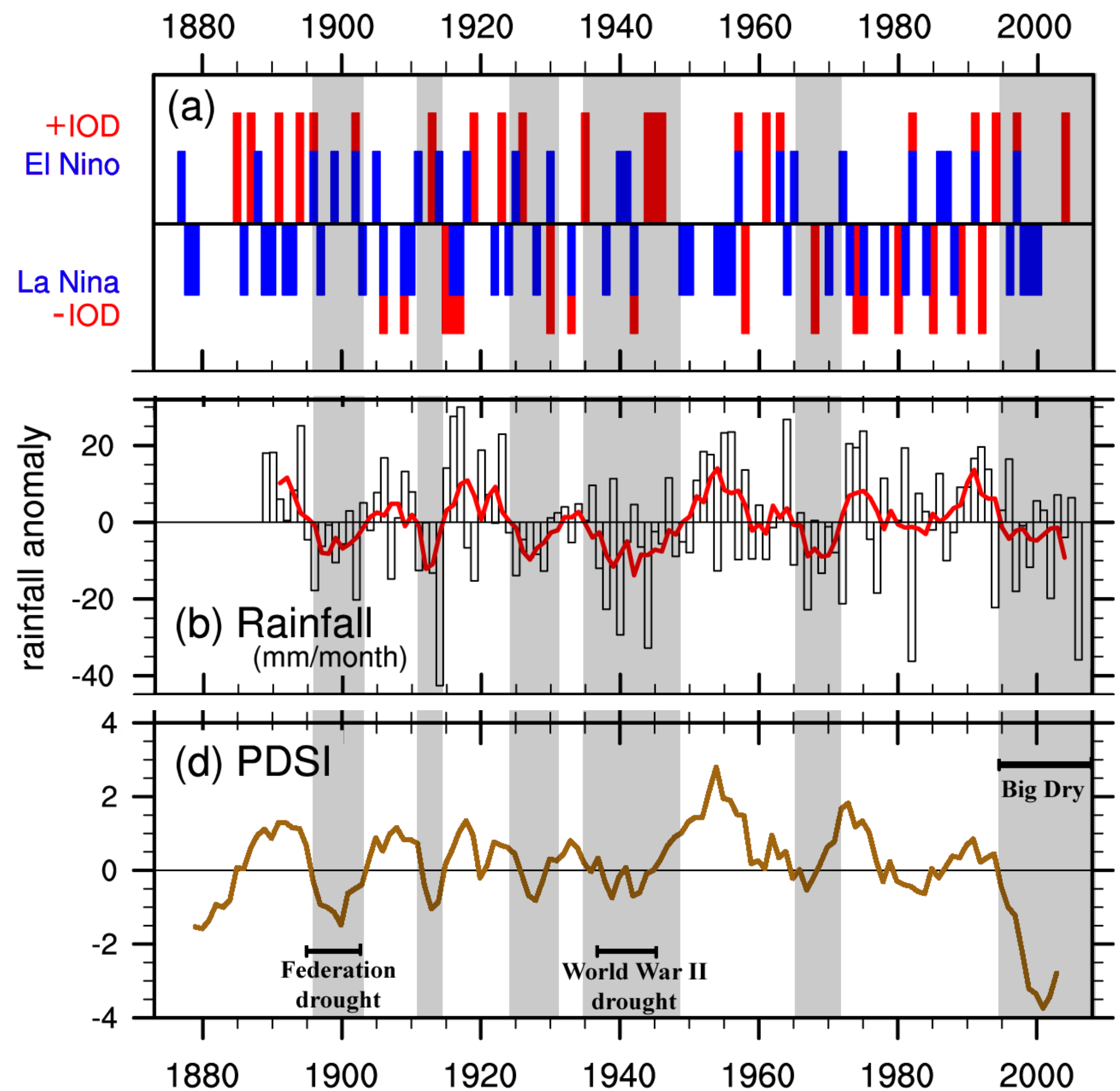
ENSO/IOD & prolonged SE Australian droughts

Rainfall anomaly

Drought Index



→ Notable **absence of negative IOD events** during prolonged SE Australian droughts

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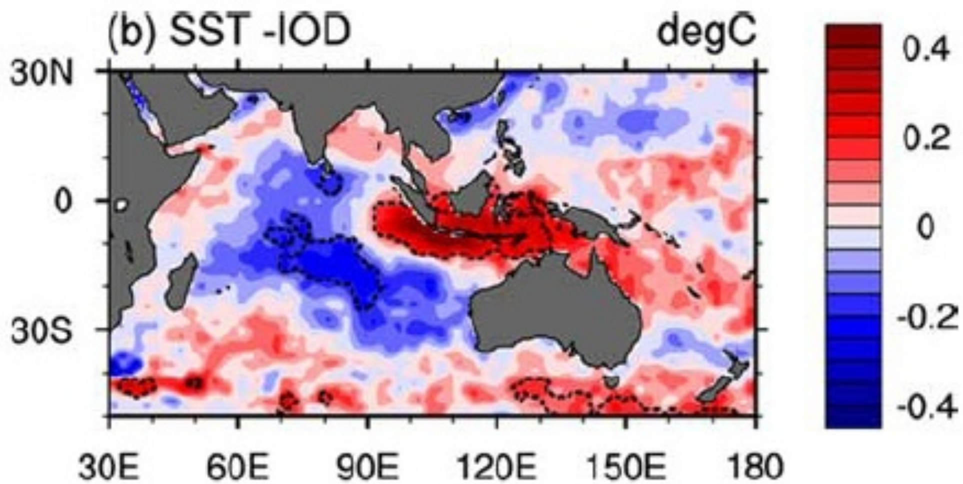
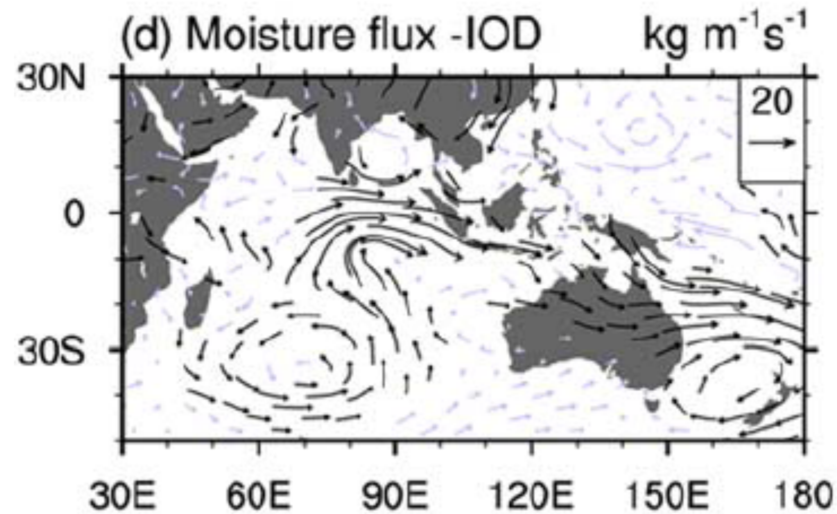
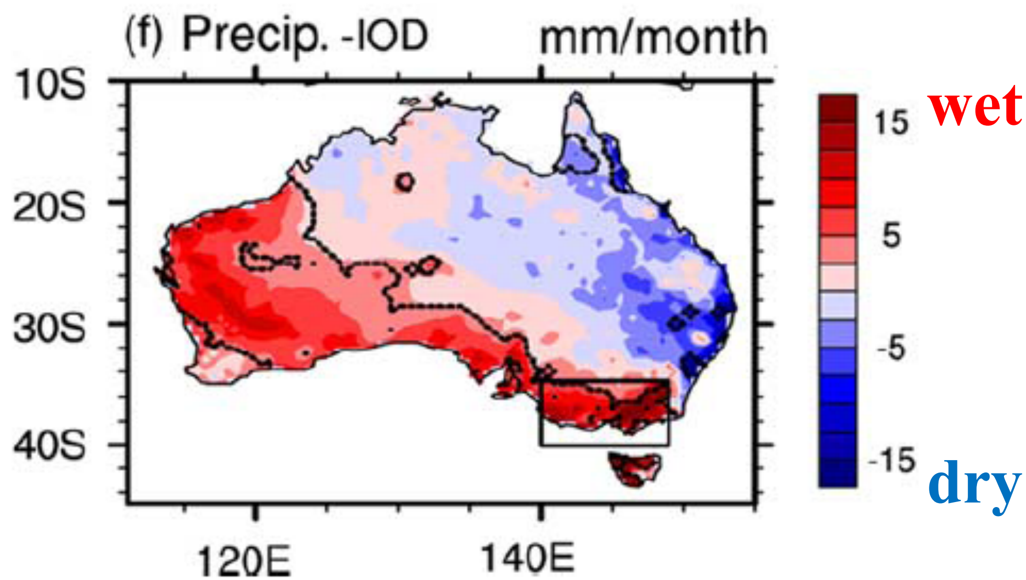
Anomalies during negative IOD events







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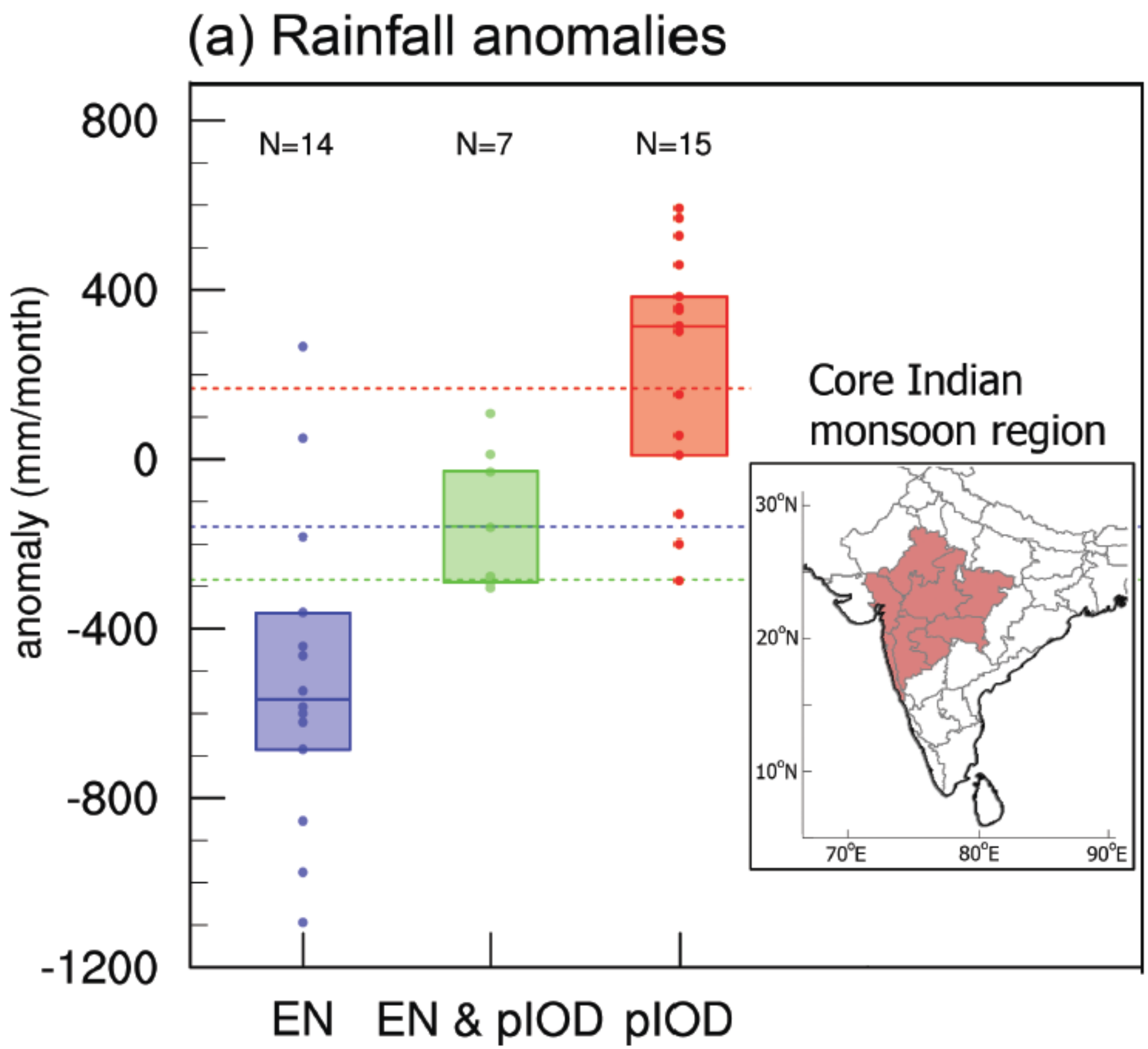
Indian monsoon rainfall anomalies during El Niño and positive IOD events



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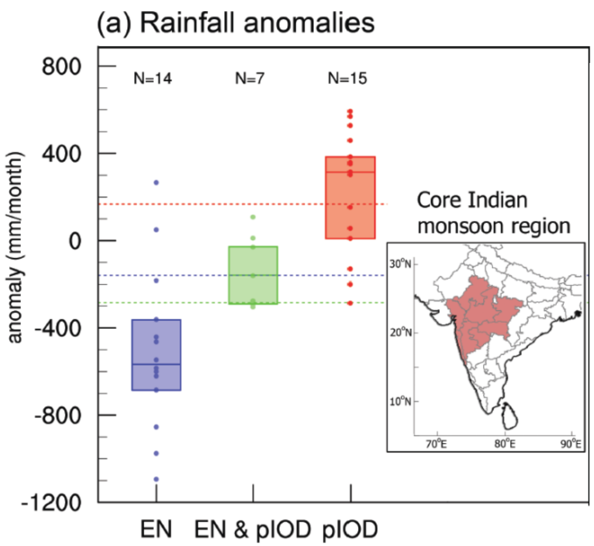
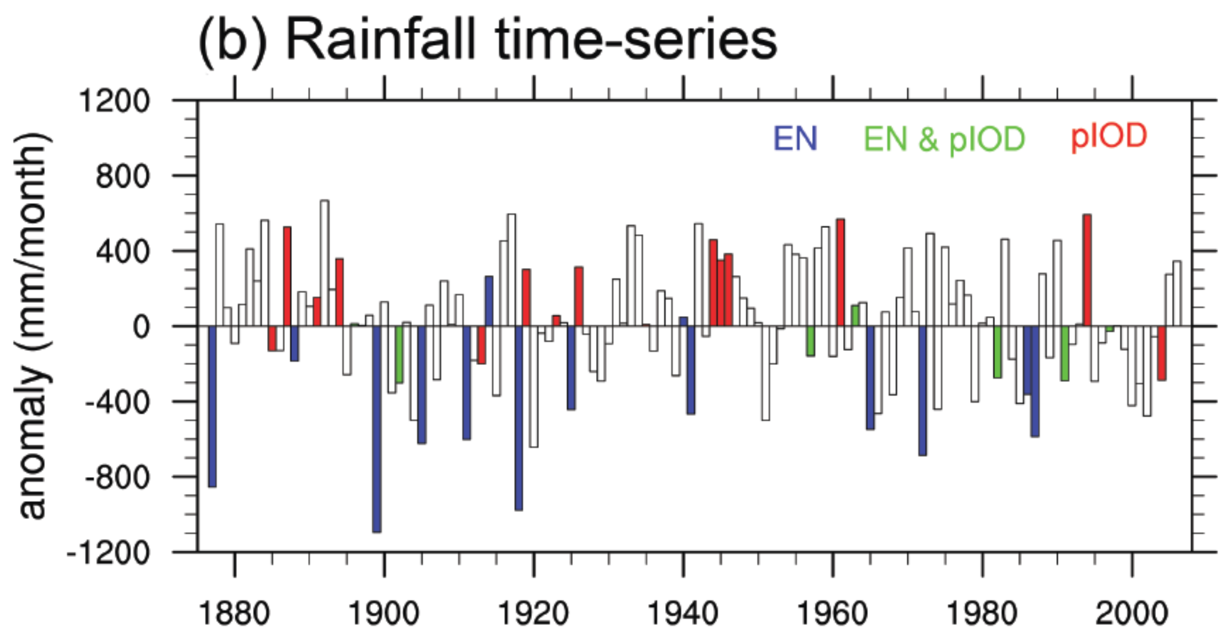
Indian monsoon rainfall anomalies during El Niño and positive IOD events





	EN & pIOD	EN	pIOD
1877–1910	2	4	4
1911–1942	0	6	5
1943–1974	2	2	4
1975–2006	3	2	2
Total	7	14	15

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Summary

- In AGCM experiments, SST anomalies in a characteristic dipole pattern modulate thermal properties of the overlying atmosphere and hence large-scale circulation over the Indian Ocean basin.

- **Anomalies in the meridional thickness gradient** change thermal wind and **baroclinic instabilities** over southern regions of Australia and can be related to shifts in the large-scale rainfall distributions over SWWA, WA and SEA.

- **Changes in large-scale moisture flux and the Walker circulation** over the tropical Indian Ocean are driven primarily by warm SST in western pole, inducing **enhanced East African rainfall and dry conditions across the Indonesian Archipelago**.

- **Prolonged SEA droughts** over last 120 years **linked more robustly to Indian Ocean** than Pacific conditions; notable absence of nIOD events.

- Decadal variation of frequency of independent and combined El Niño and pIOD events over last 130 years can account for **modulation in strength of ENSO-Indian monsoon relationship**.

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- England MH, Ummenhofer CC and Santoso A. (2006). Interannual rainfall extremes over **southwest Western Australia** linked to Indian Ocean climate variability. *J. Clim.*, **19**, 1948-1969
- Ummenhofer CC, Sen Gupta A, Pook MJ and England MH. (2008). Anomalous rainfall over **southwest Western Australia** forced by Indian Ocean sea surface temperatures. *J. Climate*, **21**, 5113-5134
- Ummenhofer CC, Sen Gupta A, England MH and Reason CJC. (2009). Contributions of Indian Ocean sea surface temperatures to enhanced **East African** rainfall. *J. Clim.*, **22**, 993-1013
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- Ummenhofer CC, Sen Gupta A, Taschetto AS and England MH (2009). Modulation of **Australian precipitation** by meridional gradients in East Indian Ocean sea surface temperature. *J. Clim.*, **22**, 5597-5610
- Ummenhofer CC, Sen Gupta A, Briggs PR, England MH, McIntosh PC, Meyers GA, Pook MJ, Raupach MR, and Risbey JS. (2010). Indian and Pacific Ocean influences on **Southeast Australian** drought and soil moisture. *J. Clim.*, in press
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For further information: http://web.maths.unsw.edu.au/~ccumm/

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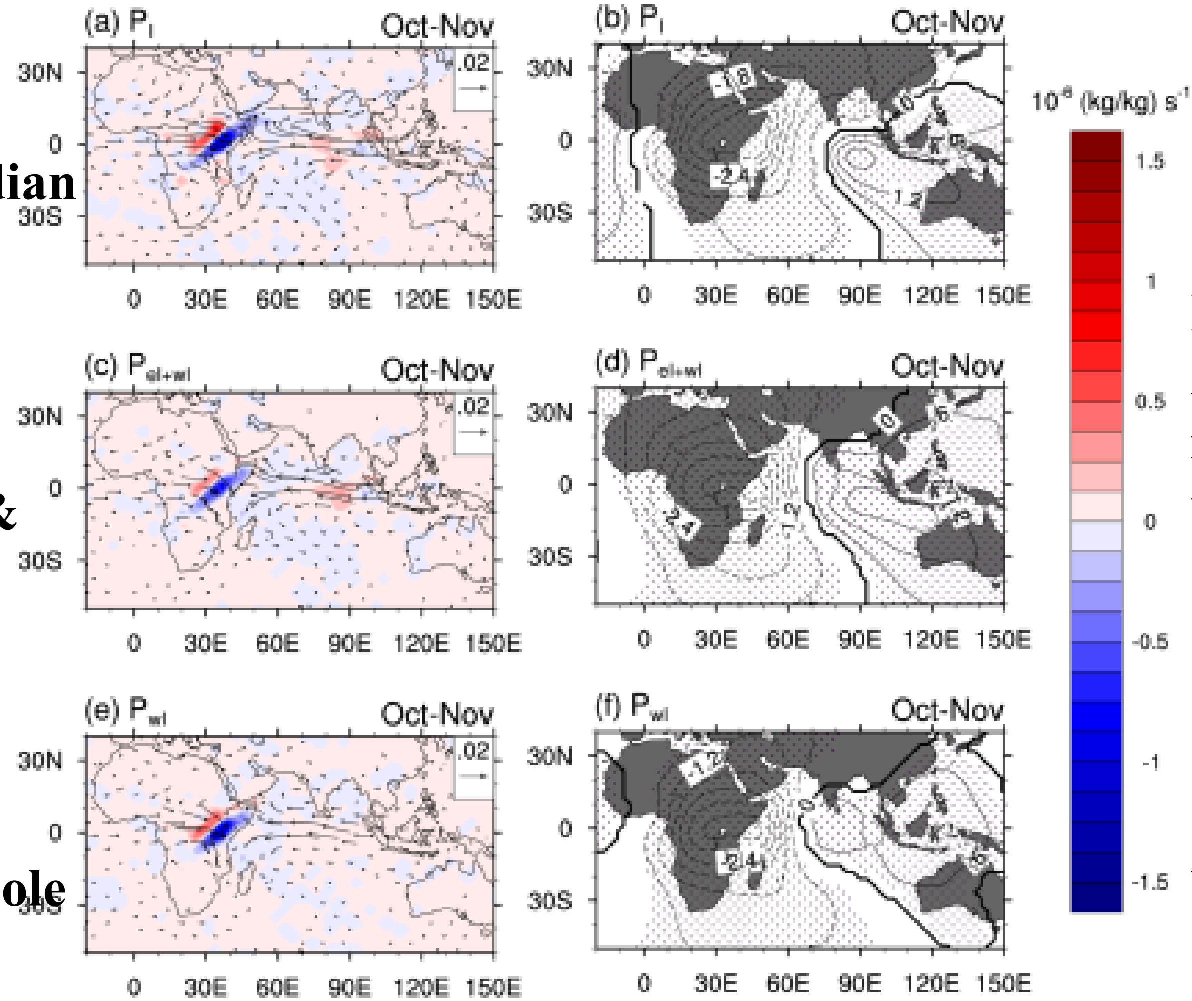
Anomalies in moisture flux and velocity potential associated with poles of SST

SSTA for **entire Indian Ocean**

SSTA for **eastern & western poles**

SSTA for **western pole**



Enhanced East African rainfall due mainly to warm western pole in eq. Indian Ocean, causing **moisture convergence** and **anomalous strengthening of Walker cell**

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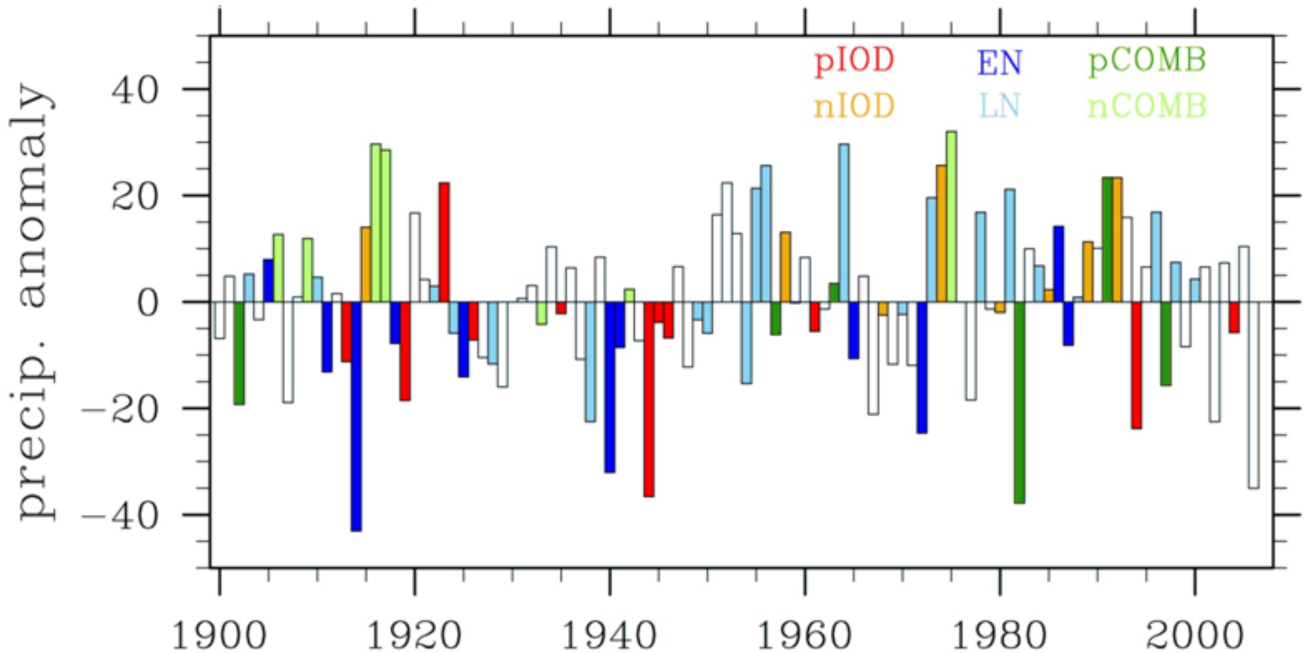
Interannual to longer-term variability

precipitation



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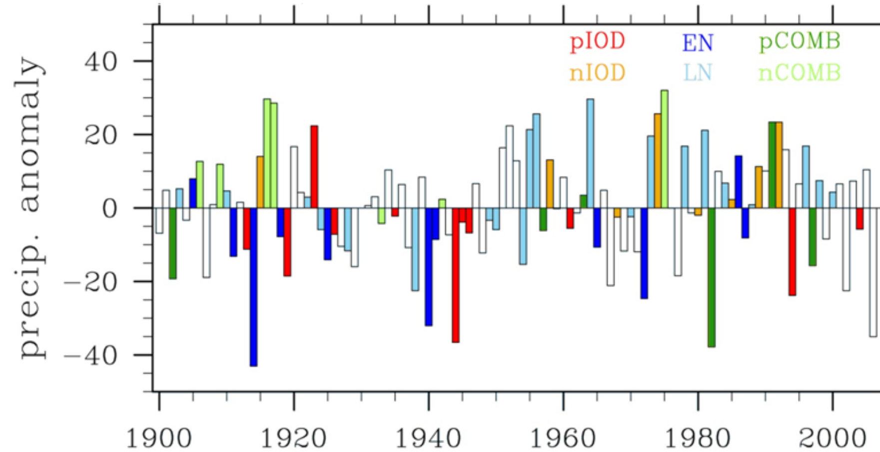
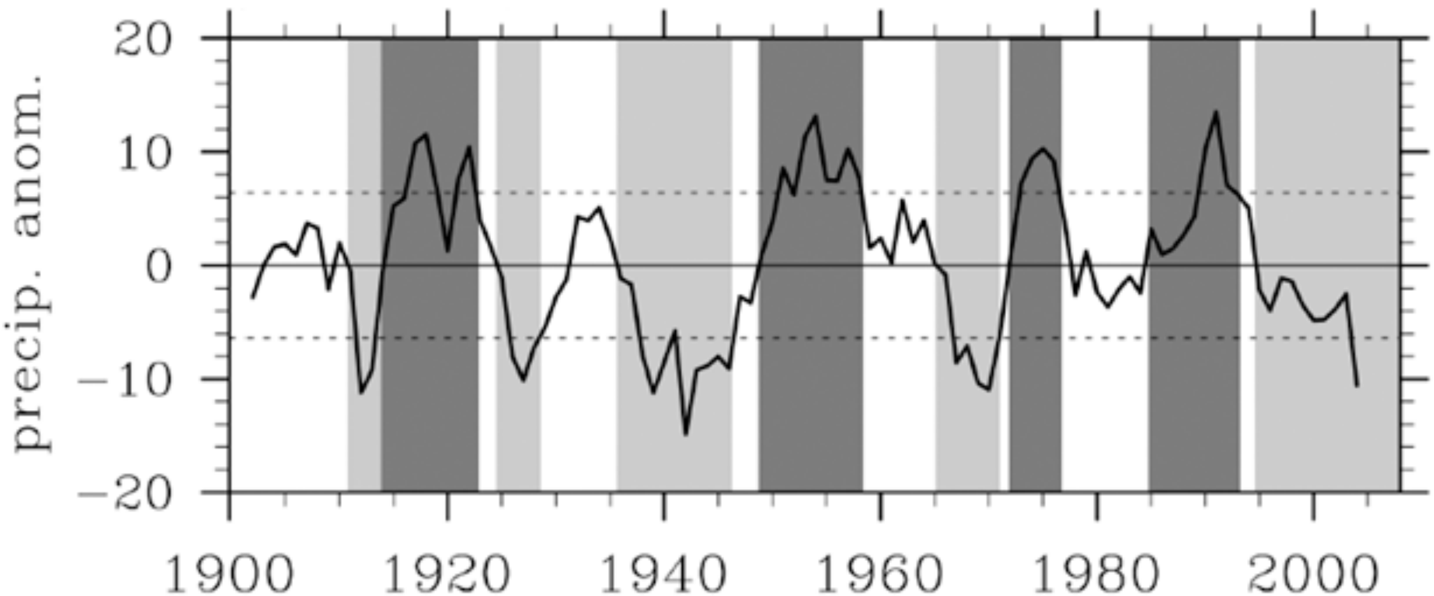
Interannual to longer-term variability

precipitation



5-year running mean of anomalies

prolonged dry and wet periods (= intervals) superimposed



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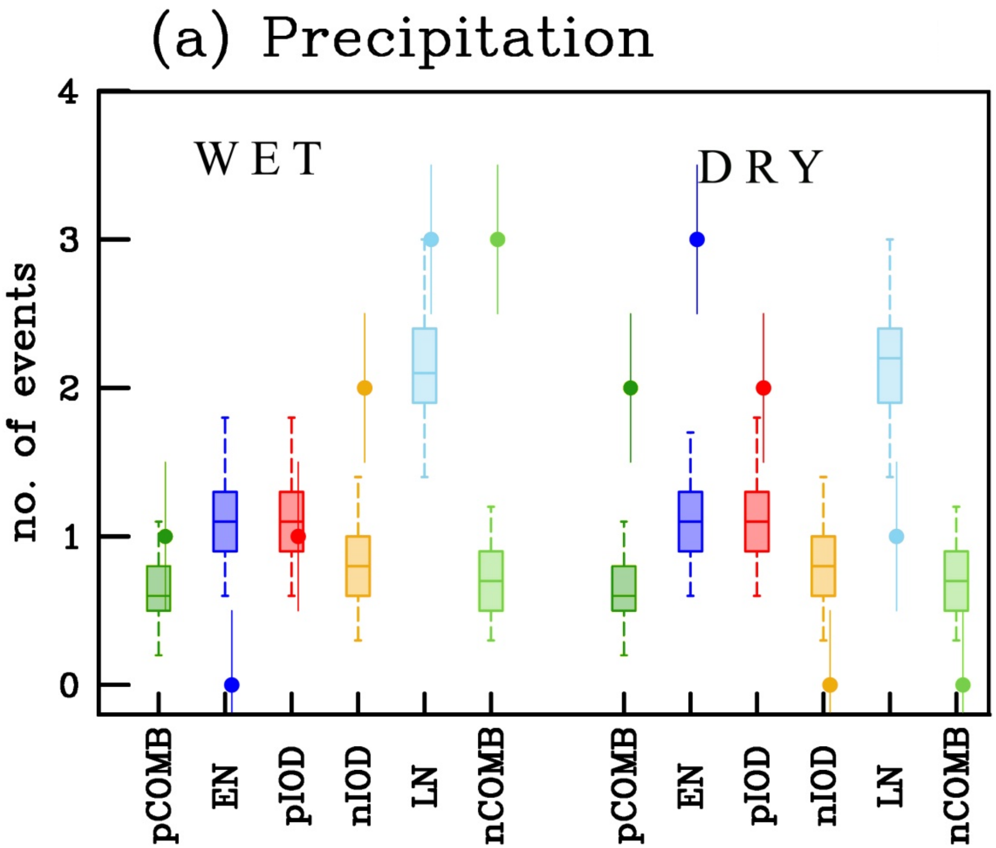
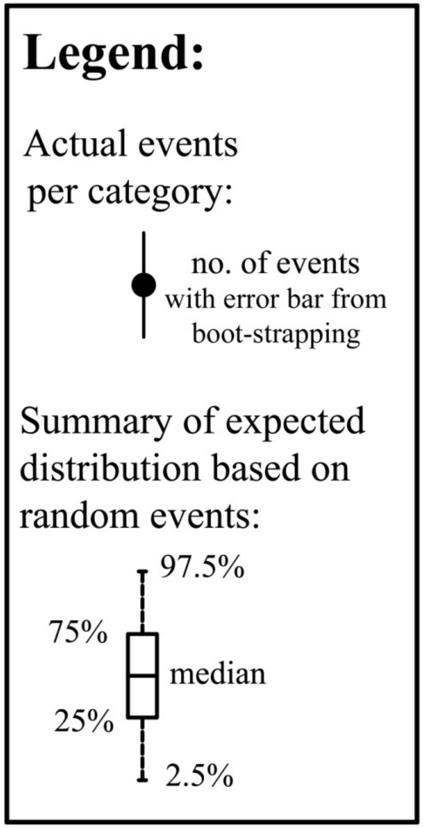
Interannual vs decadal ENSO/IOD influences





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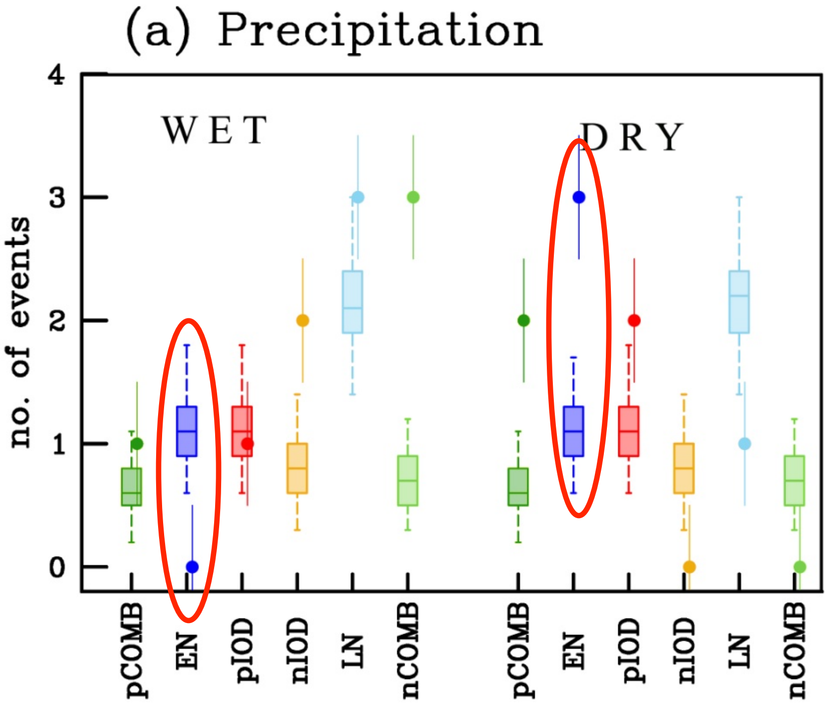
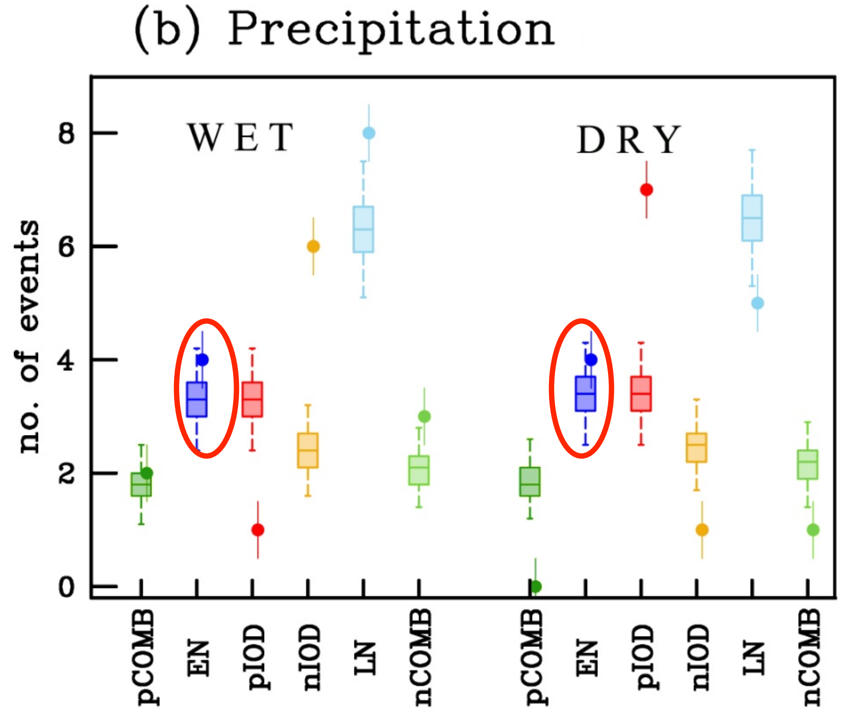


deciles



intervals

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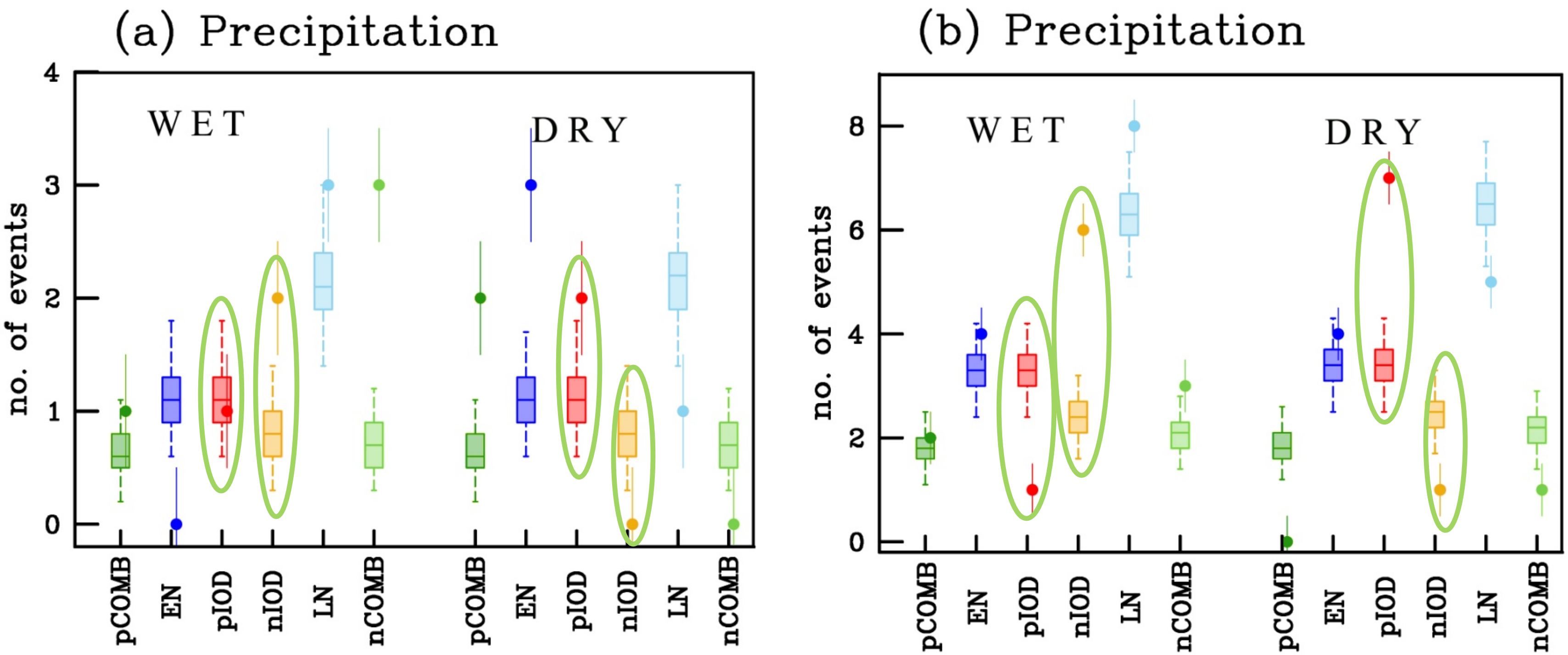
Interannual vs decadal ENSO/IOD influences



deciles **intervals**

Interannual timescales → Decadal timescales

ENSO → IOD

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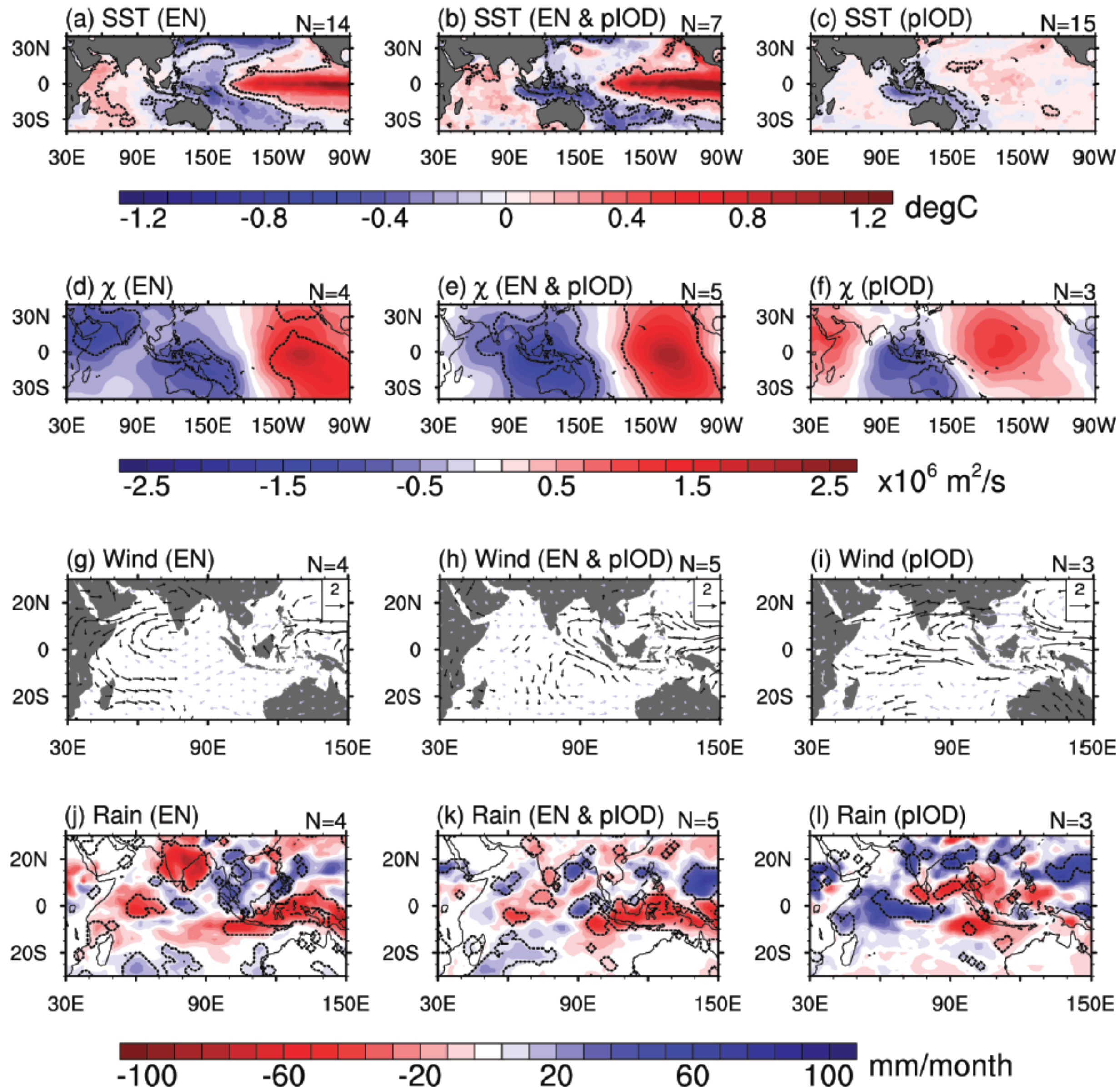
Anomalies during El Niño and pIOD events



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