Rainfall, productivity and synchronisation of climate systems in Australia

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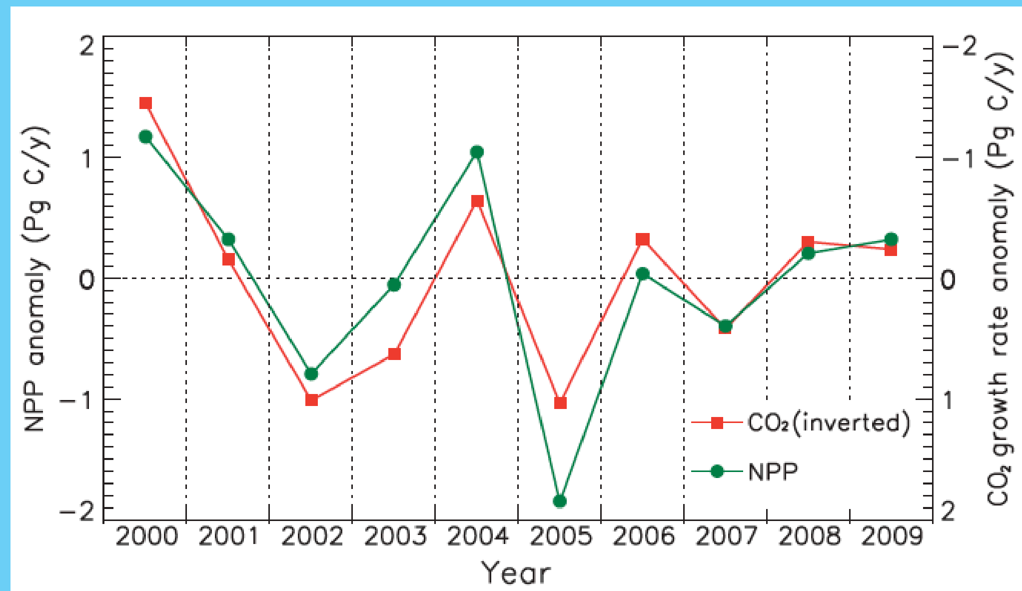
Southern Hemisphere hydroclimate

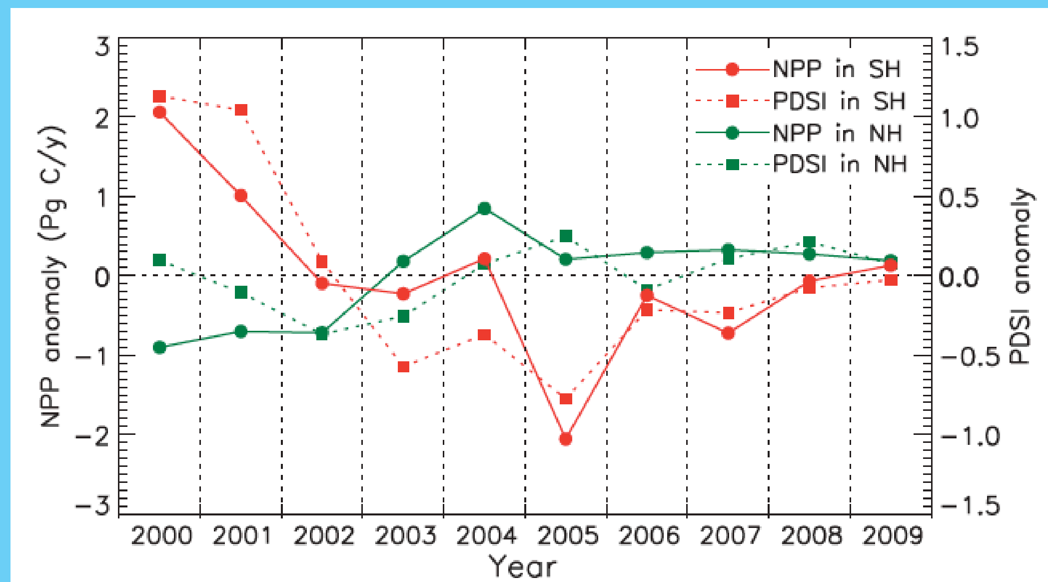
2000–2009 drought and global productivity

Strong fluctuations in global NPP
- **notable negative anomalies**
- **similar temporal pattern to atmospheric inversion:**
  - **2000: +NPP and +PDSI (wet)**
  - **2005: –NPP and –PDSI (dry)**



Similar pattern between SH NPP and drought

Northern Hemisphere no relationship



Some divergence between SH NPP and PDSI (e.g., 2004)

Provides an understanding of antecedent conditions for what was to come

[Zhao and Running 2010]

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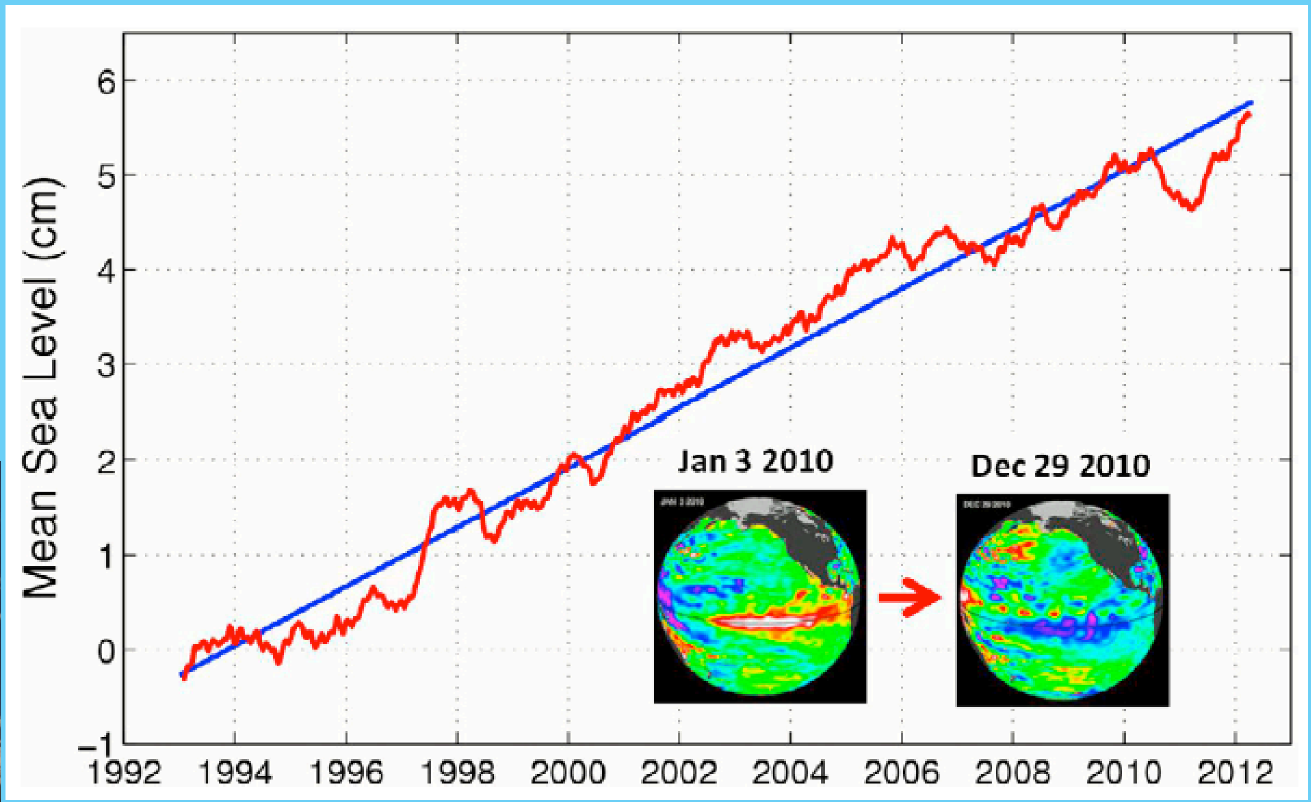
Global anomalies: ocean level decline
2010–2011

Strongest sustained La Niña in over 90 years (since 1917) **[Boening et al. 2012]**
5 mm drop in ocean level **[Boening et al. 2012]**
Increase in total continental water mass through 2012 **[Fasullo et al. 2013]**
- **Runoff returned additonal water to the ocean from other continents**



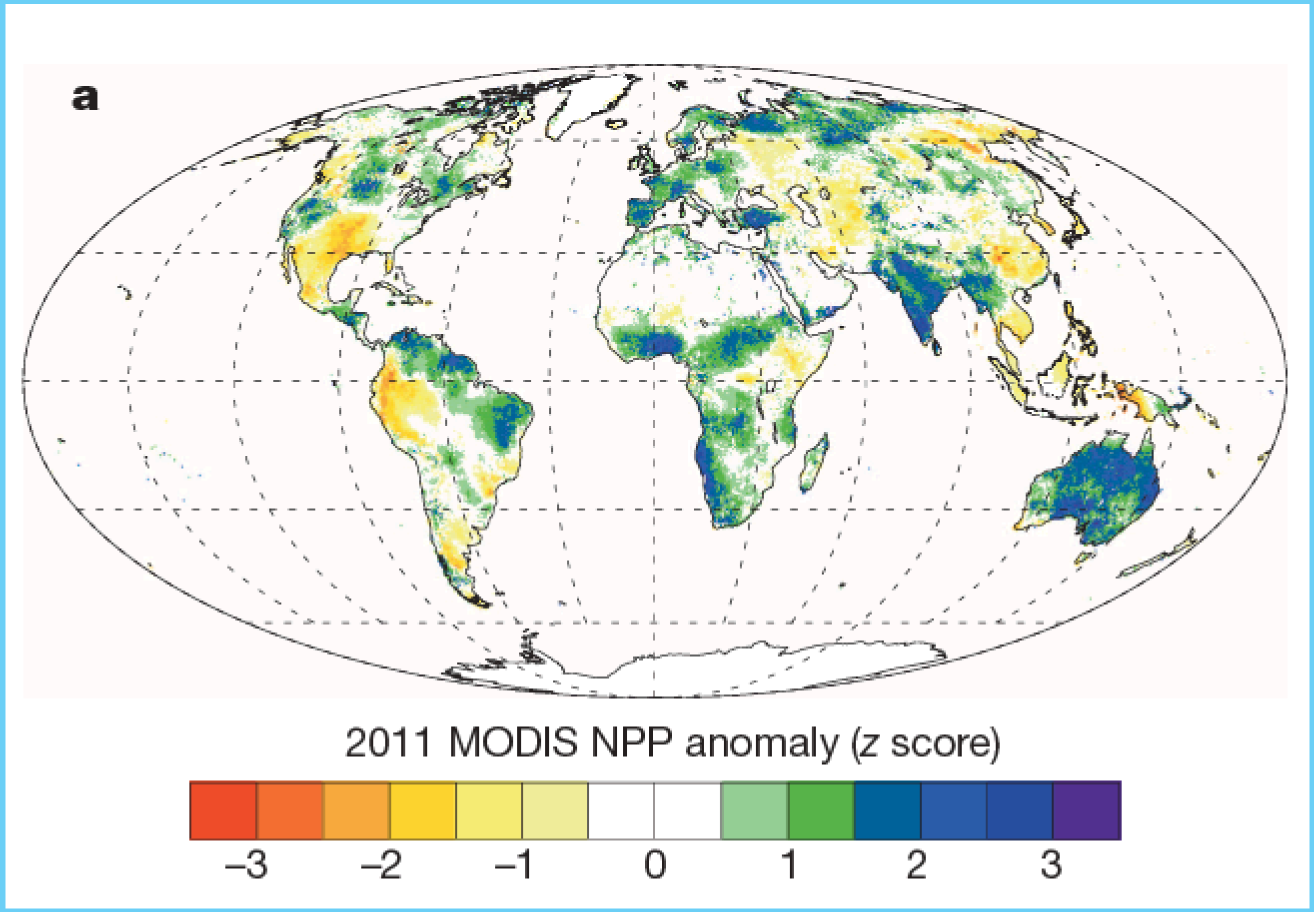
[Boening et al. 2012]

2011 global land C sink anomaly

Extraordinary C sink identified in semi-arid regions of the Southern Hemisphere attributed to La Niña [Poulter et al. 2014]

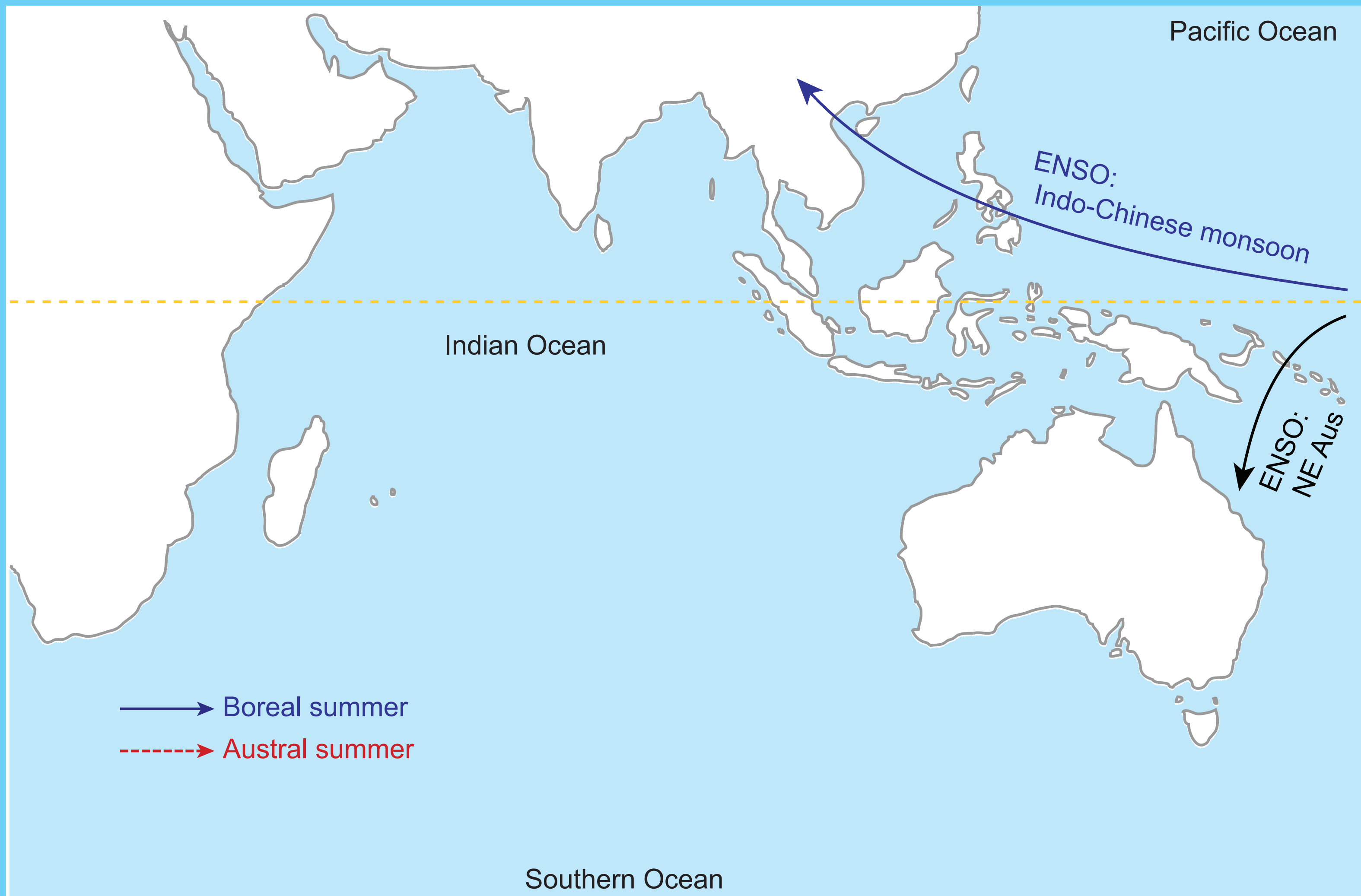
- **57% attributed to Australian aridlands**
- **Remainder attributed to southern African aridlands and temperate S America**

Direct measurements of enhanced C sink and productivity [Cleverly et al. 2013, Eamus et al. 2013]



[Poulter et al. 2014]

El Niño–Southern Oscillation



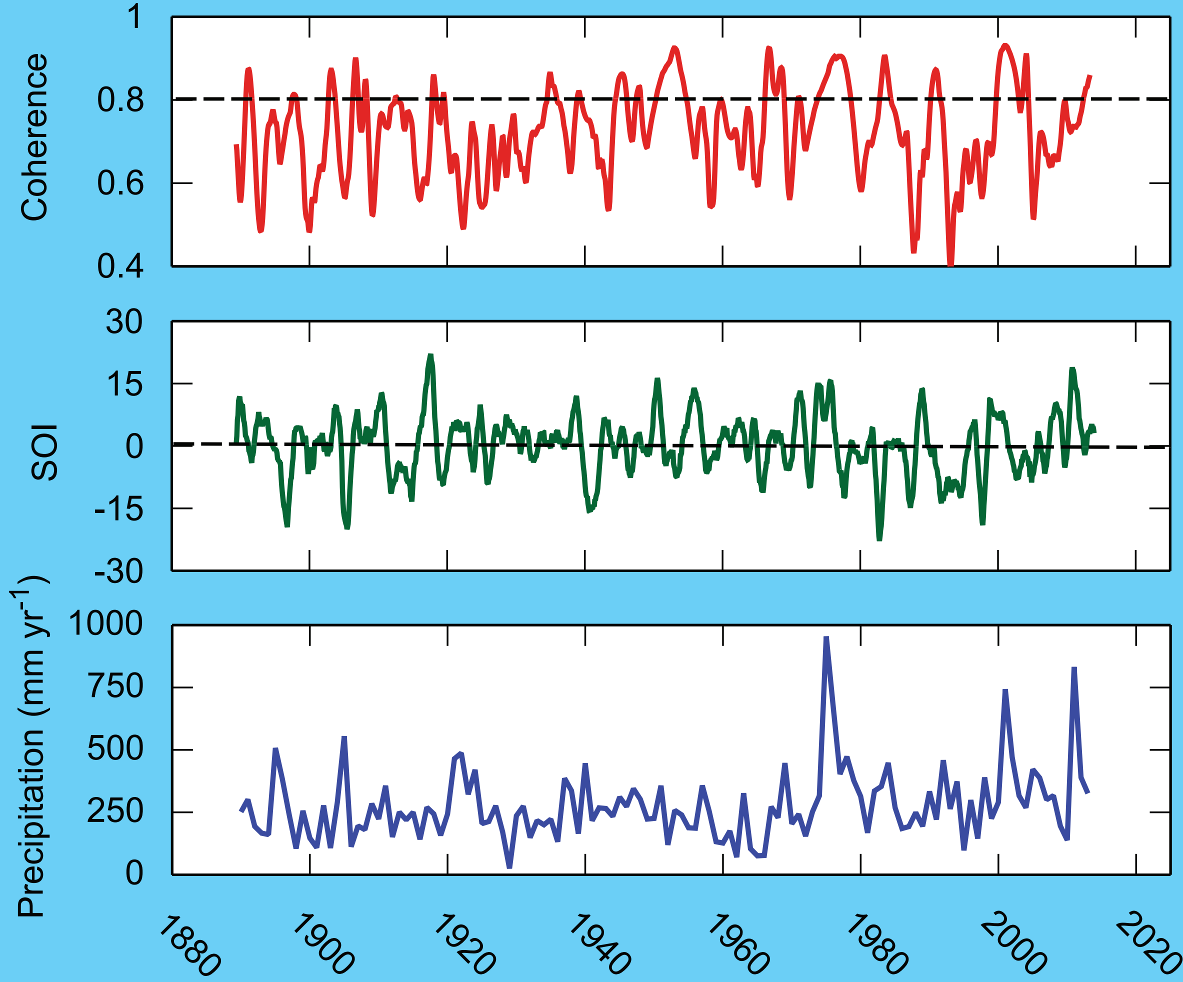
Direct baroclinic effects in QLD [Cai et al. 2012]

General moisture field via indirect Rossby waves [Risbey et al. 2009]

How closely is La Niña correlated to precipitation?

Was this a case of a 1-point correlation?

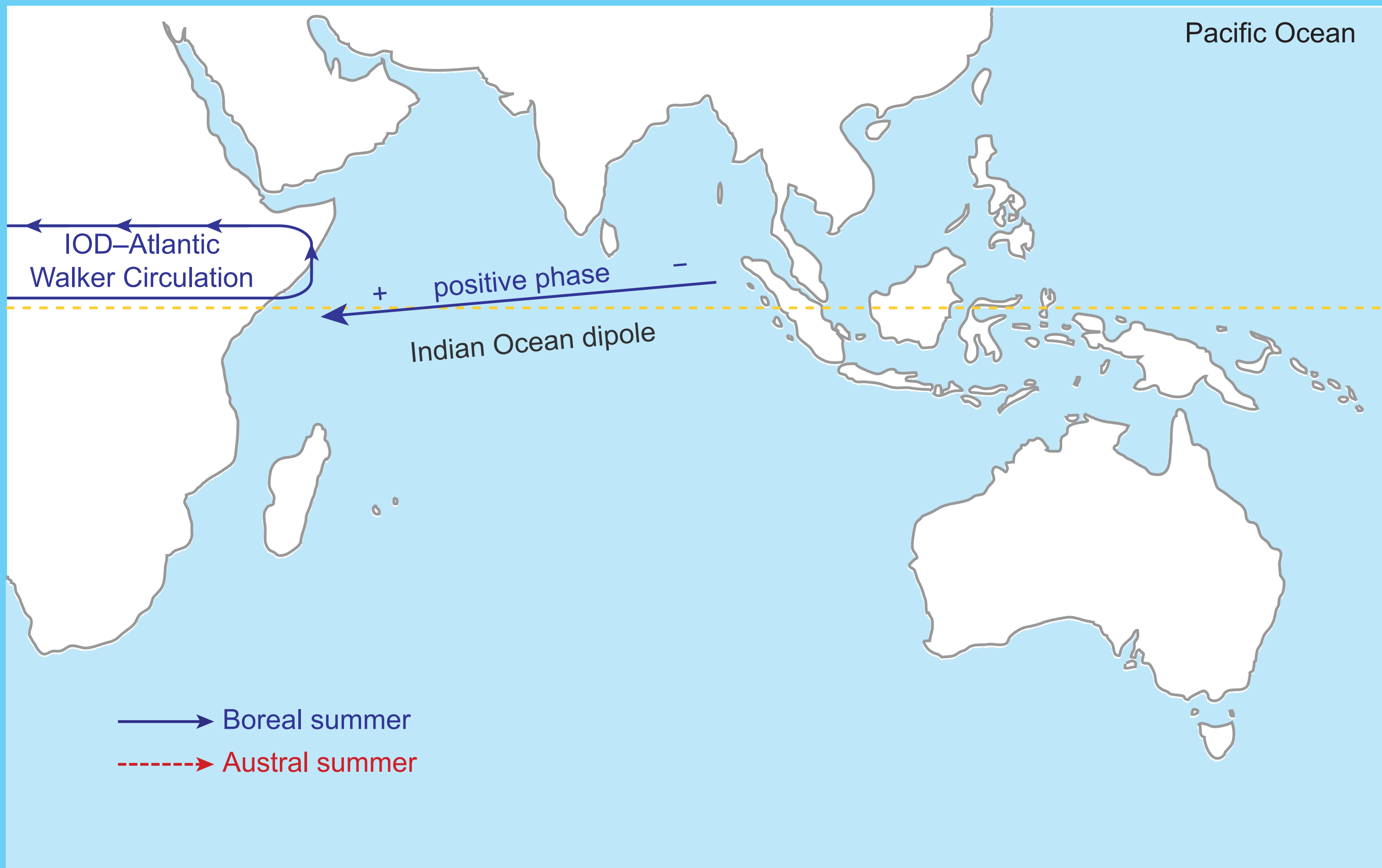
Temporal ENSO–precipitation correlation



Coherence: squared correlation
Significantly different from zero at ~ 0.8
Previous extreme La Niña resulted in small but significant increase in precipitation
ENSO is not the only driver of precipitation

Indian Ocean Dipole

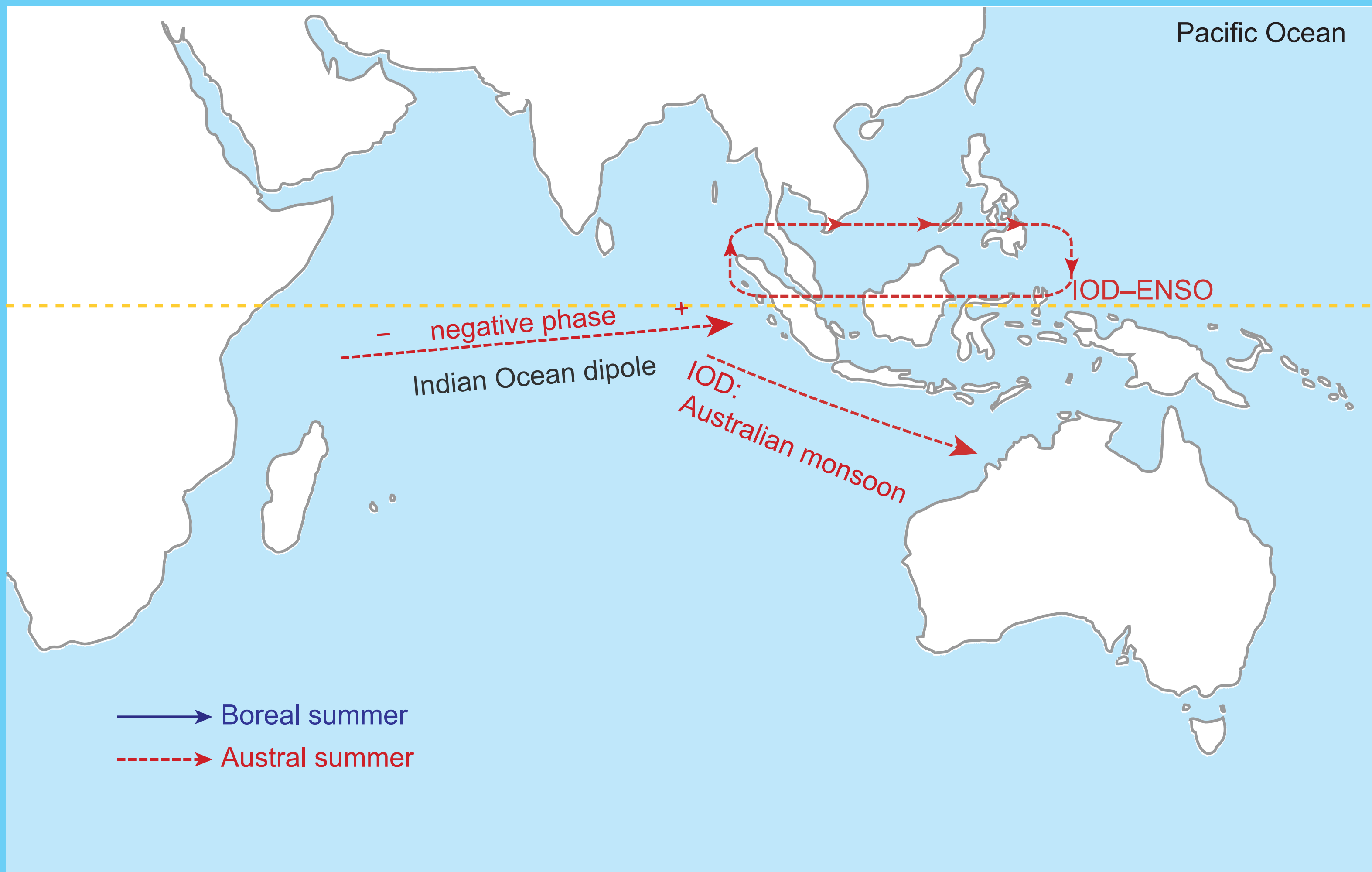
Boreal summer



†[Numerous references]

Shoaling of cold water in eastern IO creates an equatorial dipole
Convection in western IO created by lifting from warm pole
Convection drives formation of IOD–Atlantic and cross-IO Walker Circulation
Cold pole blocks precipitation in NW Australia

Indian Ocean Dipole
Austral summer

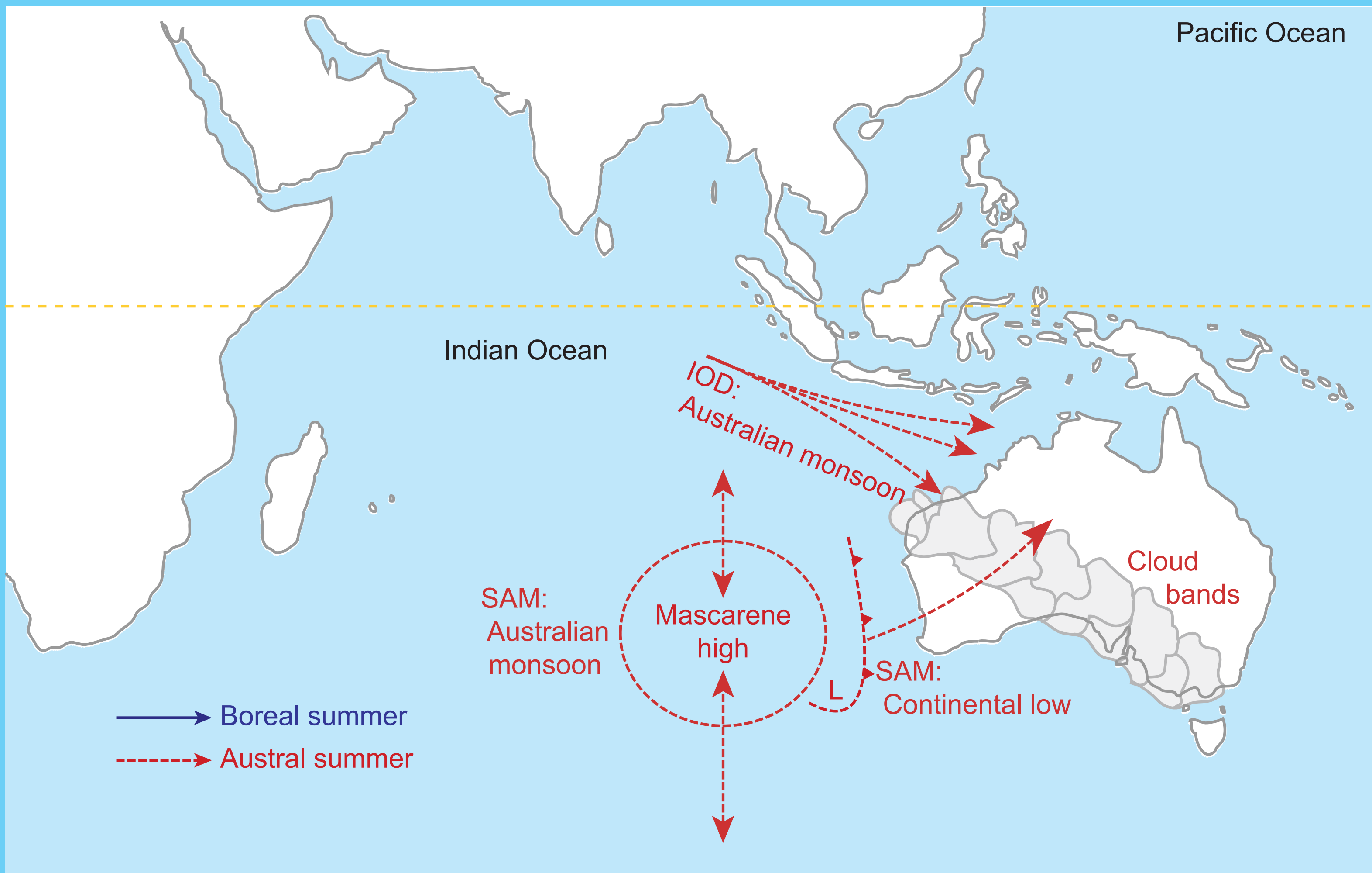


†[Numerous references]

Convection centre crosses IO eastward along the equator
IOD strongly involved in development of the Australian monsoon depression
IO–PO Walker Circulation connects IOD and ENSO

Southern Annular Mode

Mascarene High

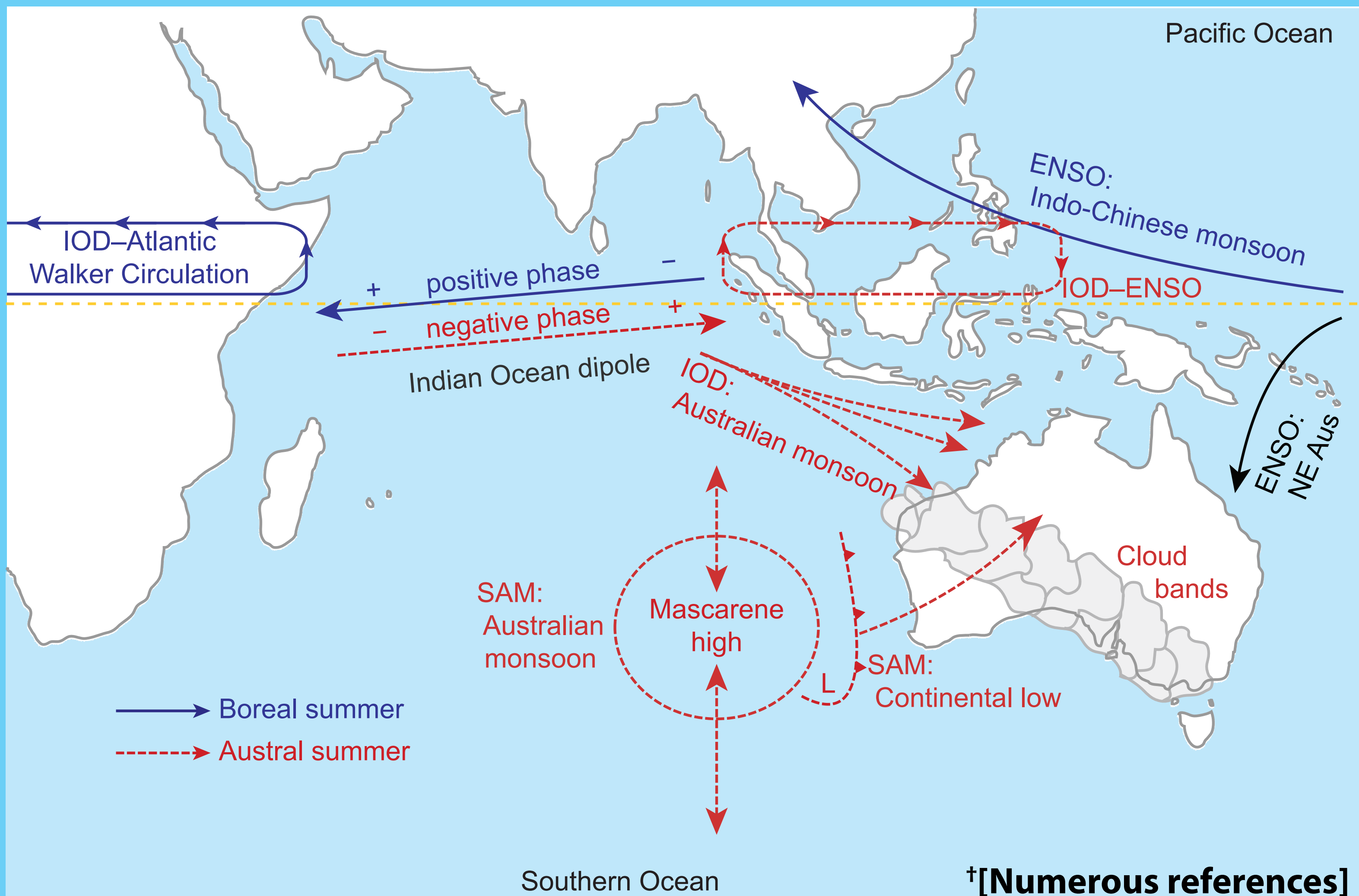


†[Numerous references]

Position of MH impacted by SAM and AMOC–northwestern IO
MH affects N–S position of monsoon depression and continental Low
SAM associated with subtropical ridge, cloud bands and weather in SE Australia

Climate modes

ENSO, IOD and SAM



†[Numerous references]

ENSO: general moisture field via indirect Rossby waves

IOD: strength of monsoon depression

SAM: location of monsoon landfall via MH

Individually related to rainfall occurrence, not amount [Pui et al. 2012]

Hypotheses

- **Interaction of regional climate modes explains variations in precipitation amount**
- **Combined effects of climate modes will be reflected in continental weather patterns**
- **Pattern of green leaf production will reflect continental weather patterns**

Methods

wavelet PCA: Niño3.4, dipole mode index, southern annular mode index

wavelet coherence: wPC *versus* precipitation

NCEP re-analysis: 500 hPa geopotential heights above zonal average

MODIS EVI: 2011 EVI anomalies

Climate mode interactions

wavelet PCA

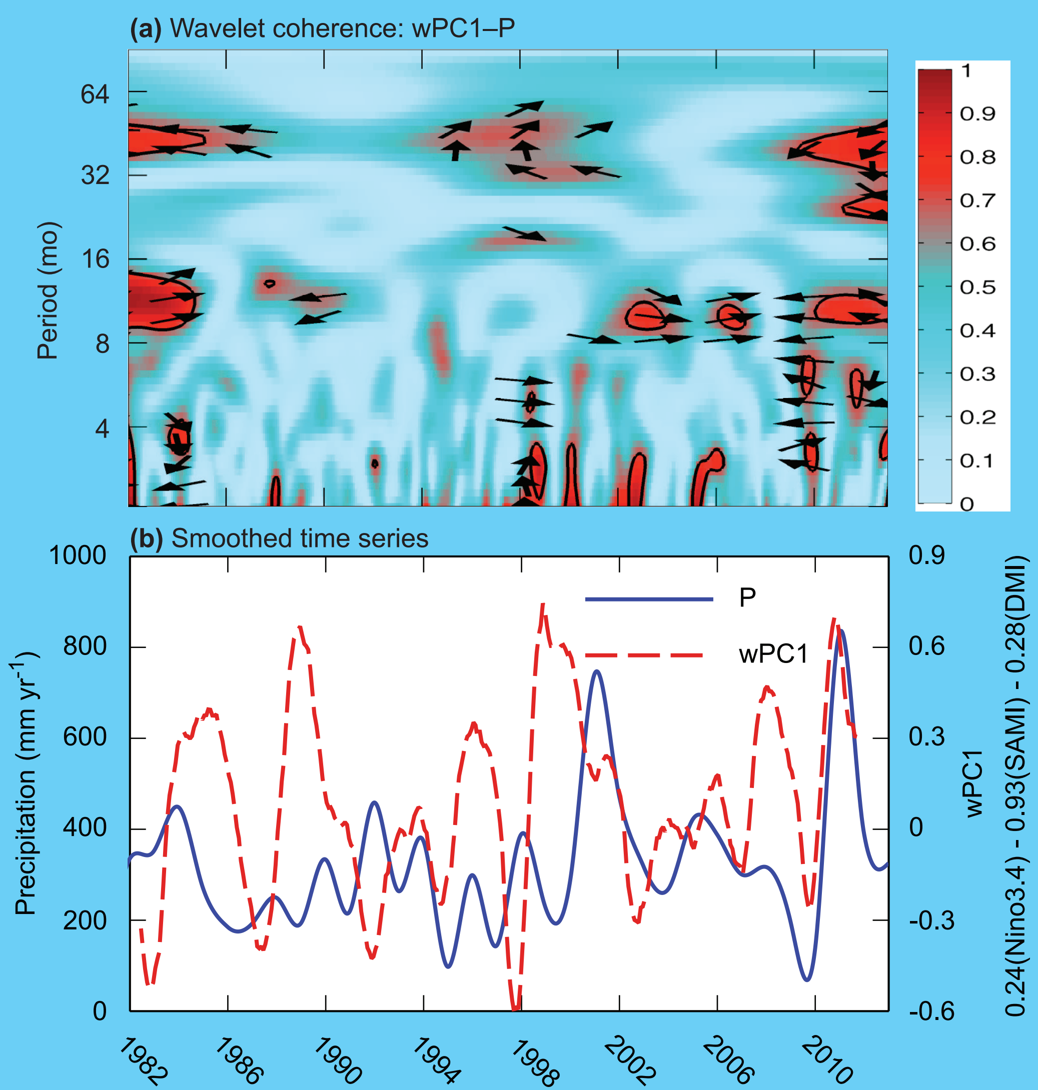
Date range	wPC1 (% of total)	wPC2 (% of total)
1982–1998	0.99 SAMI − 0.16 Niño3.4 − 0.03 DMI (70.5)	−0.16 SAMI − 0.95 Niño3.4 − 0.25 DMI (24.6)
1998–2013	−0.99 SAMI + 0.17 Niño3.4 + 0.04 DMI (80.2)	−0.17 SAMI − 0.98 Niño3.4 − 0.05 DMI (15.7)
1982–2013	−0.93 SAMI + 0.24 Niño3.4 − 0.28 DMI (>99)	

SAM explains the largest amount of variability amongst climate modes

IOD explains very little variability except over long timescales (1982–2013) and in wPC2 of 1982–1998

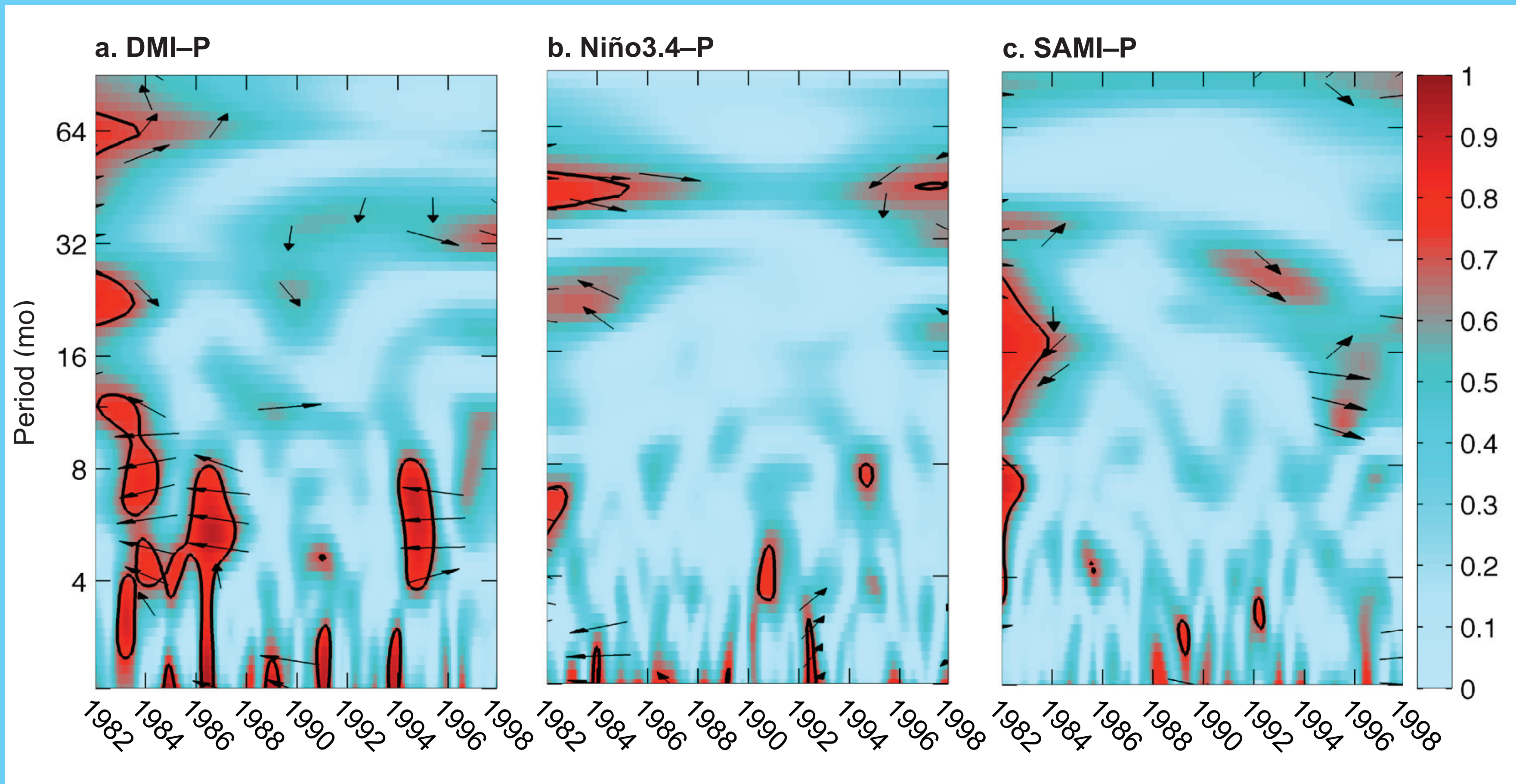
Overall: half of the variability due to SAM, one-quarter for each of ENSO and IOD

Climate drivers
IOD, ENSO, SAM



- **Correlation between wPC1 and precipitation identified by wavelet coherence (squared correlation)**
- **Synchronisation of climate drivers beginning in 1999 associated with increased coherence between rainfall amount and climate**
- **Synchronisation associated with large fluctuations in rainfall, both very wet and very dry years**

Pre-synchronisaation
1982–1999



Correlations strongest with IOD

Key ENSO–precipitation coherence on seasonal and sub-seasonal timescales during El Niño (dry correlation)

SAM has little direct relationship with precipitation

Weather system interactions
Monsoon depression × continental low

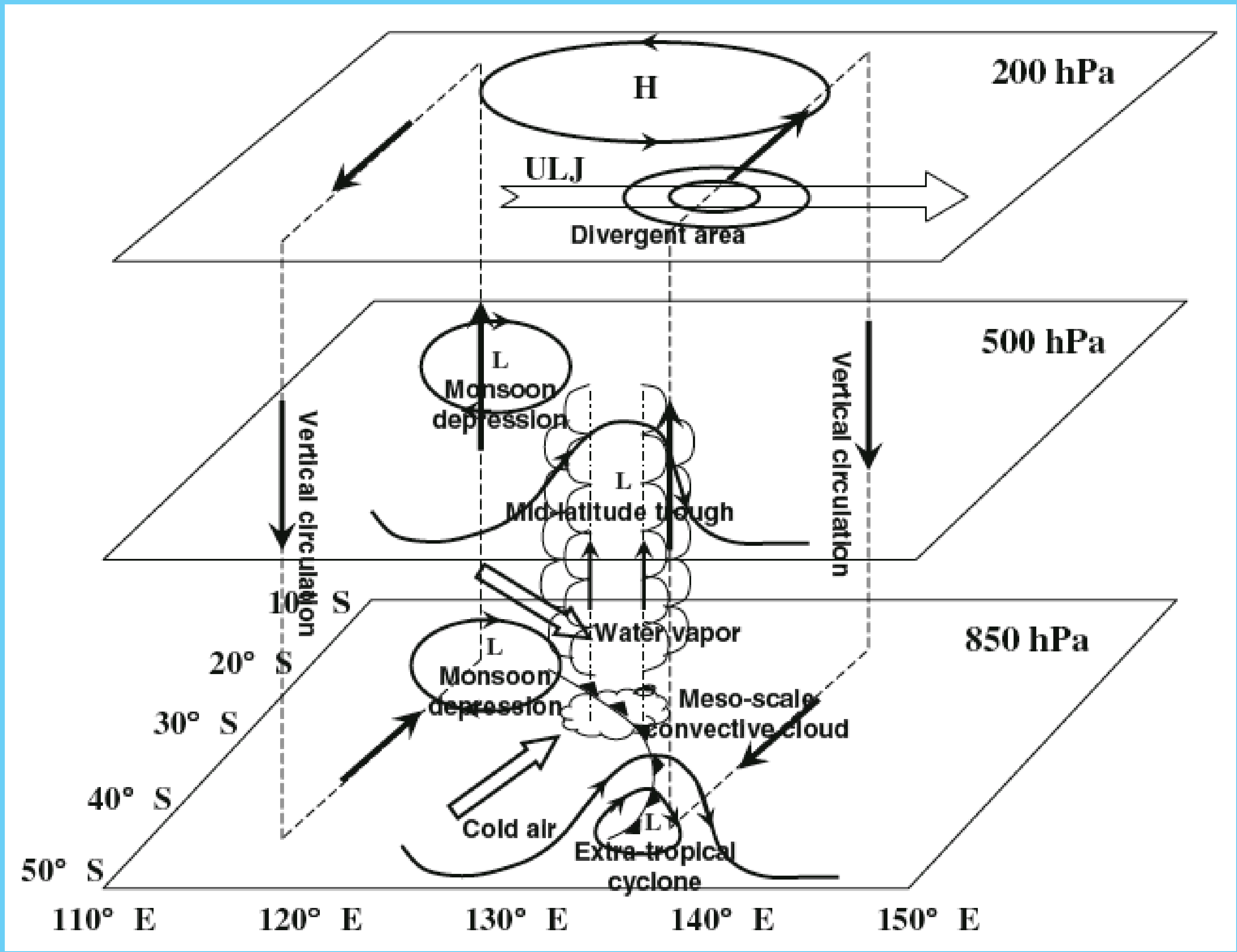
Synchronisation period

Mechanism: 2005 wet

Continental low intercepts the monsoon depression

Monsoon depression rises well above the 500 hPa level

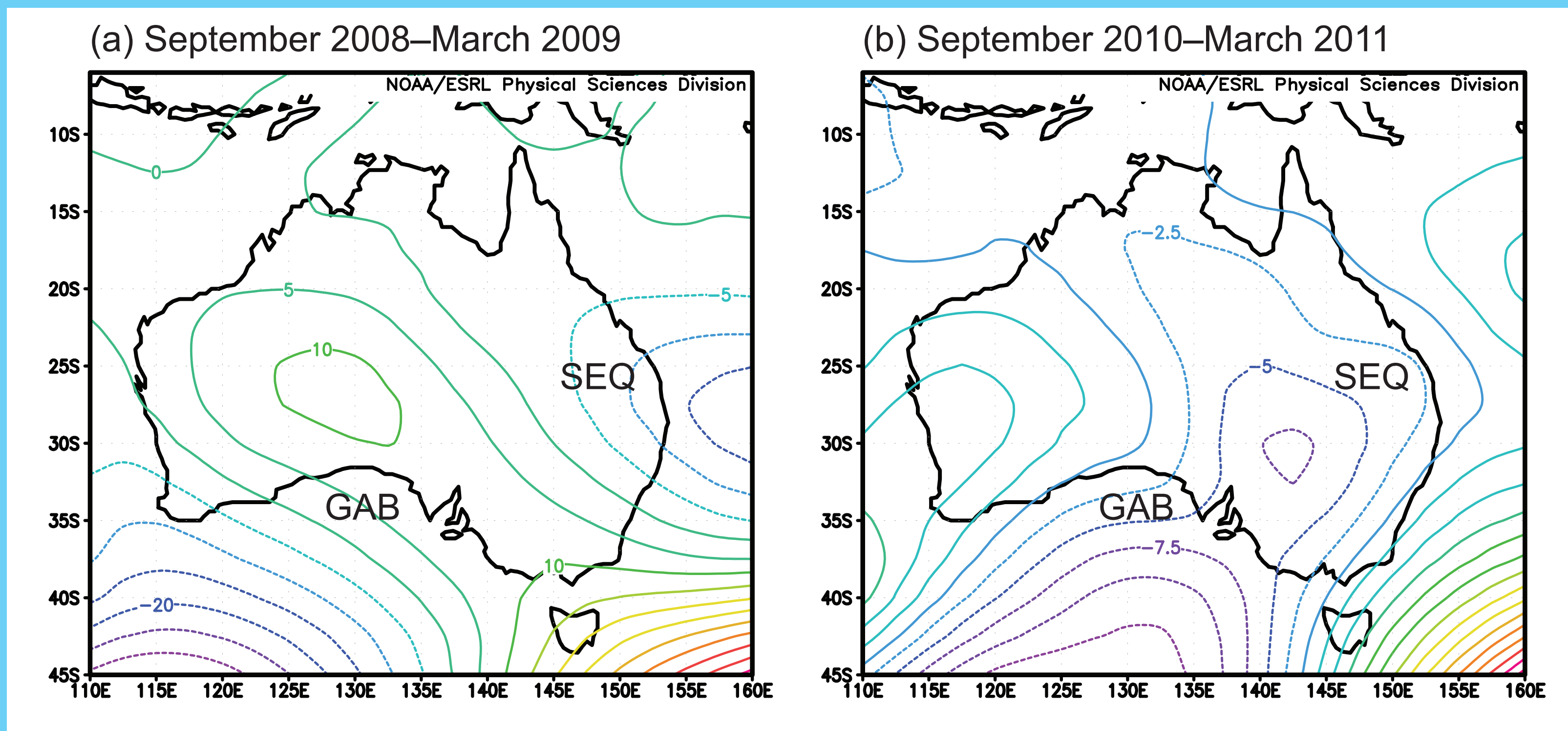
High-elevation core of intense vorticity in moist air



[Kong and Zhao 2010]

Weather patterns

2009 dry versus 2011 wet

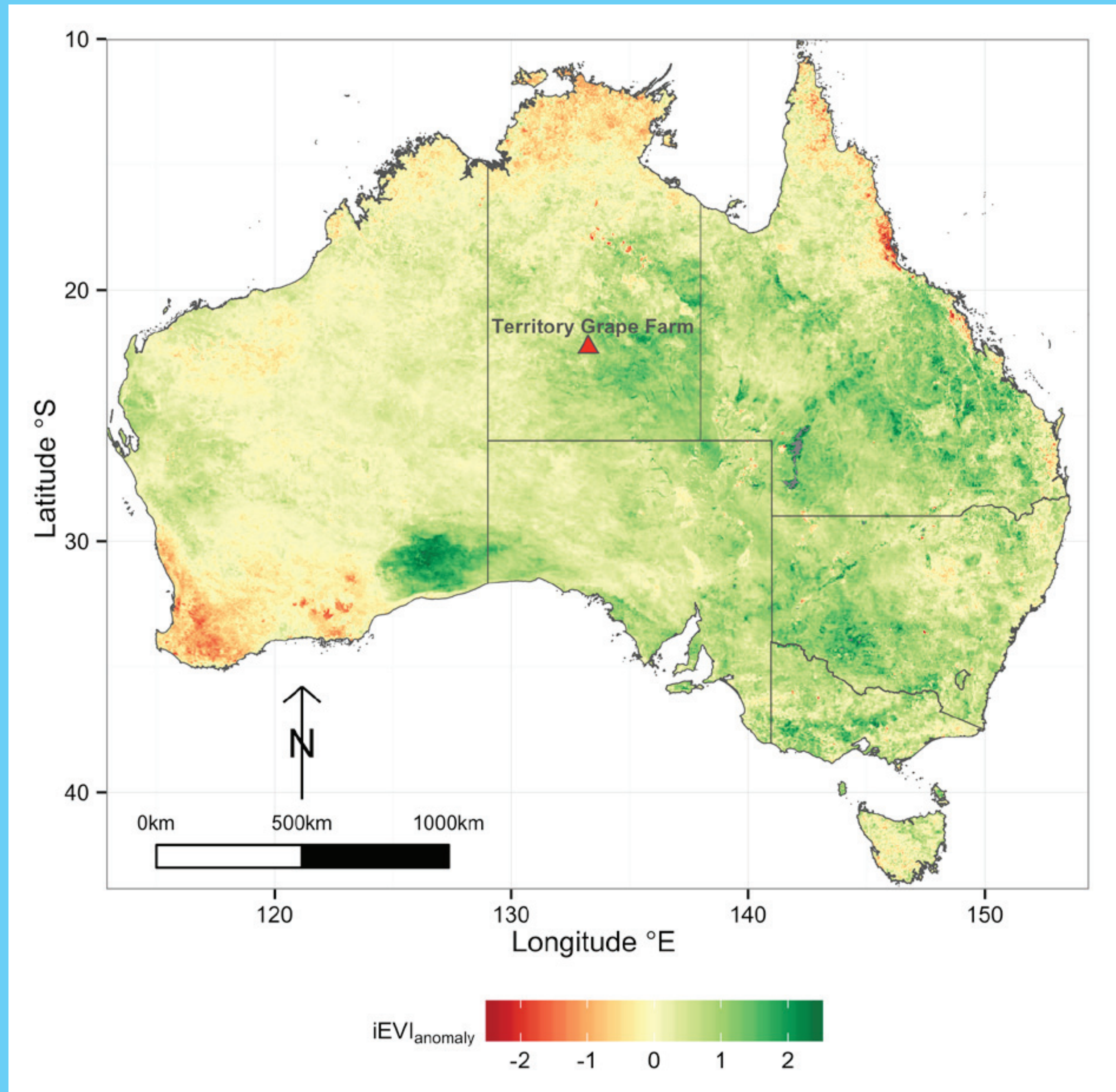


2008–2009: Ridge over central Australia, depression pushed north of 10–15 °S, vorticity in southeast Queensland

2010–2011: Deep vorticity from northwestern Australia (monsoon depression) to the Great Australian Bight, voticity node in southeast Queensland

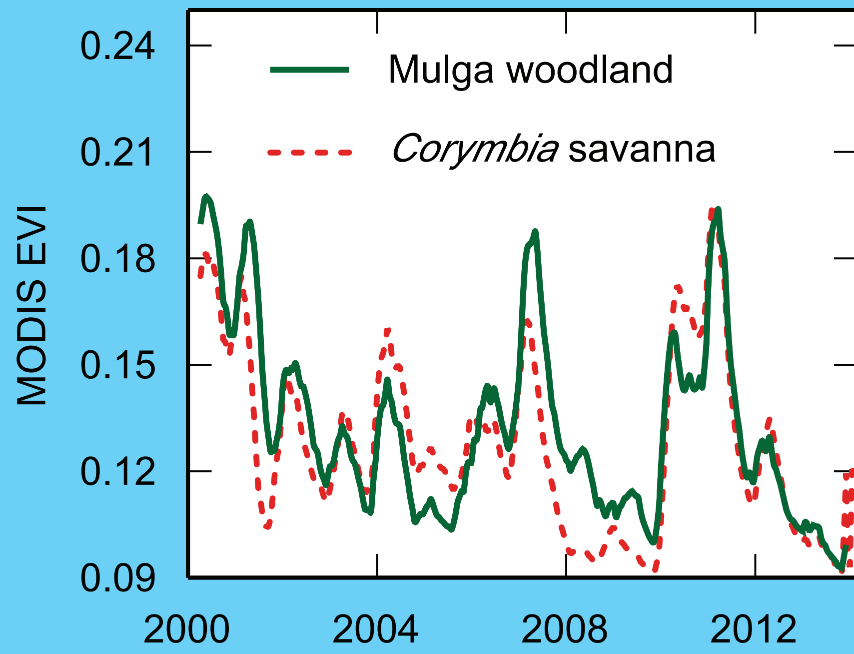
Continental greenness

- **Pattern of 2010–2011 EVI anomalies reflects continental weather patterns,**
- **except in the tropical wet savanna (e.g., Howard Springs), which is light limited during the wet and canopy LAI maintained during the dry [Whitley et al. 2011]**



Ti Tree catchment

Contributions by Mulga and Spinifex



- **Large inter-annual variations in EVI**
- **Neither ecosystem consistently exhibits larger responses during wet years**
- **Dry years: EVI approaching un-vegetated limt**

Conclusions

H1: Interaction of regional climate modes explain variations in precipitation:

Verified. Synchronisation of climate modes and precipitation began in 1999. In previous years, precipitation driven primarily by the Indian Ocean dipole.

H2: Reflection of climate modes in continental weather patterns:

Verified. Direct influences of IOD and ENSO observed in 500 hPa vorticity. Indirect effect of SAM on position of the monsoon depression apparent in wet and dry years.

H3: Pattern of green leaf production reflects continental weather patterns:

Verified. Pattern of green leaf production followed weather patterns, and two of the dominant semi-arid vegetation types (Mulga and Spinifex) responded with extraordinary resilience to antecedent drought during precipitation anomalies.


Thank you
Questions?