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Challenges in modeling the Australian Monsoon System

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Overview

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Work I want to cover:

Observational features of the AMS
Modelling representation
Important processes and teleconnections: ENSO and IOD
What about the MJO?
Our model – ACCESS – recent improvements

With contributions from:

Dr Jo Brown
Dr Rob Colman
Dr Huqiang Zhang
Dr Charmaine Franklin

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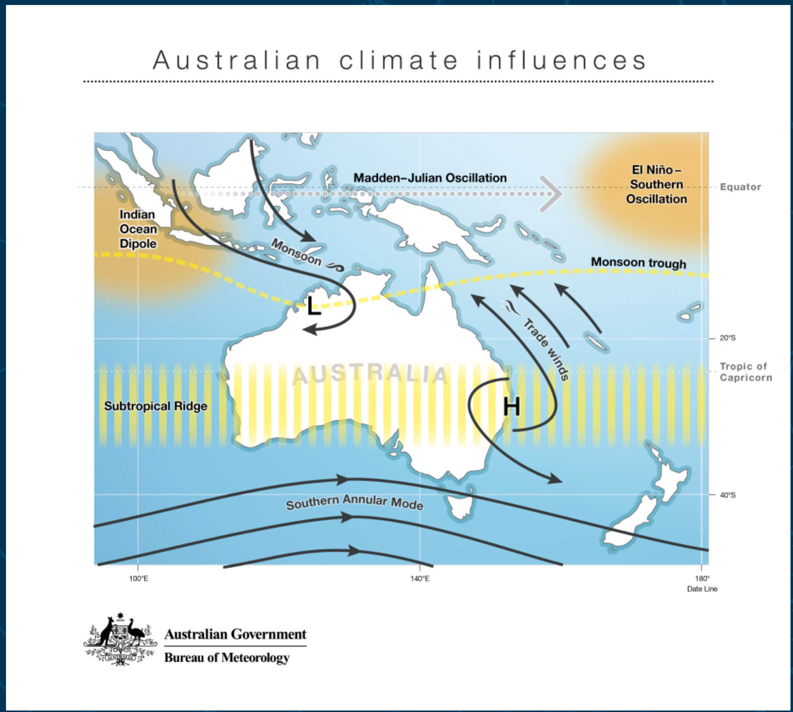
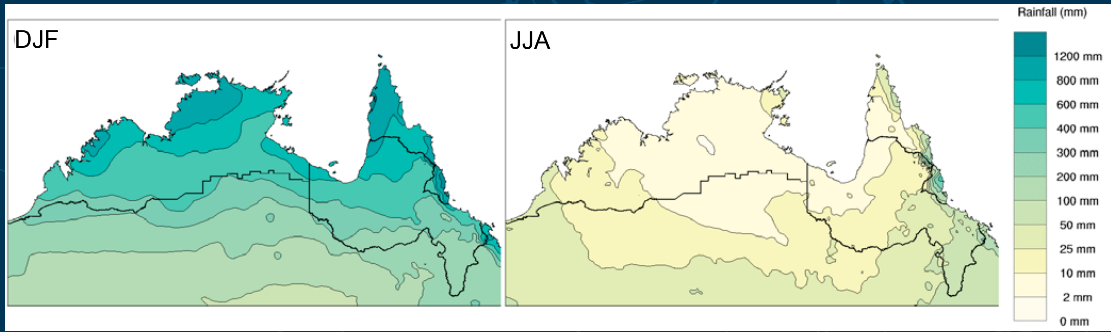
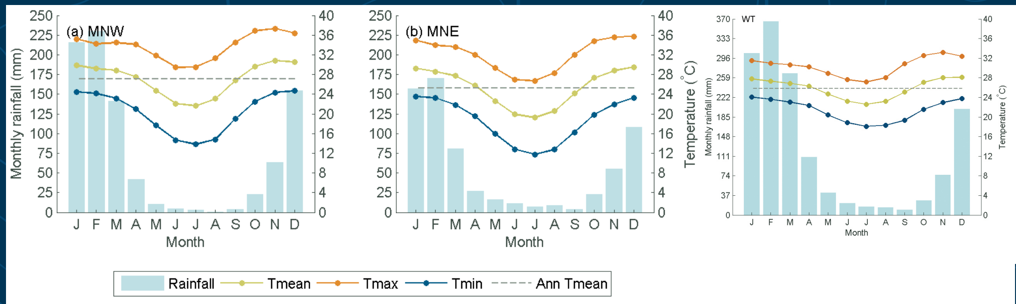
Observed Australian Monsoon characteristics

What are the processes involved in Australian Monsoon?



Observations – (1986-2005)





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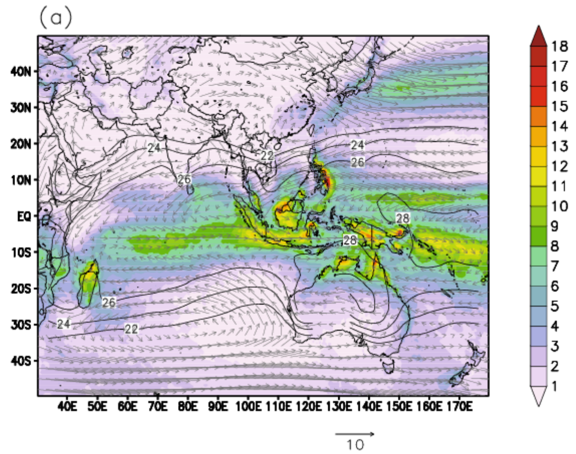
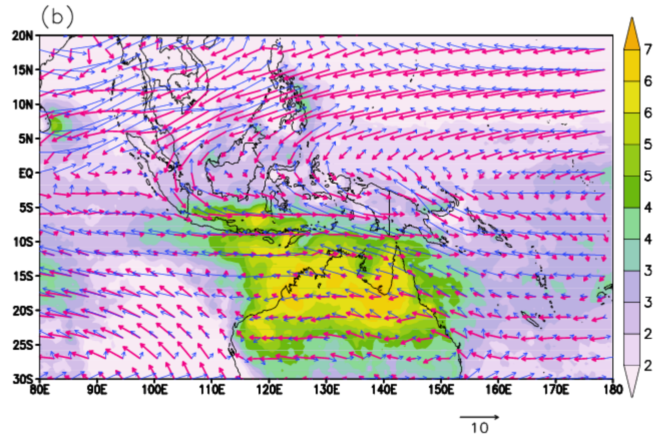
DJF rainfall (shading, mm/d) from TRMM (1998-2011), ERA40 winds (850hPa, 1958-2002, ms^{-1}) and surface temperature (HadCRU-T4, 1979-2010, °C) over the tropical domain.

TRMM and ERA40

Fraction of annual total rainfall falling in DJF (shading, in %) and ERA40 climatological winds for January (**red** arrows) and July (**blue** arrows).





Few summary statements

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- Compared to the Asian monsoon, the Australian monsoon is relatively weak and its southward penetration is limited to tropical Australia around 15°–20°S.
- The rapid changes in zonal wind and the establishment of sustained rainfall events usually start from late September to early October around south Sumatra to Timor and nearby waters, and then progress southeastward, **typically reaching northern Australia in late December**

Its climate **is affected by many competing processes** such as
→ state of the tropical Pacific (in particular ENSO and/or ENSO Modoki)
→ tropical Indian Ocean (Indian ocean dipole, IOD, and basin-wide warming)
→ Also important are Asian-Australian monsoon interactions with Asian aerosols
→ Seasonal continental warming associated with regional land-sea thermal contrasts.
→ In addition, middle latitude synoptic systems can also play an important role

Such complexities lead to limited modeling and forecasting skills in current weather and climate models

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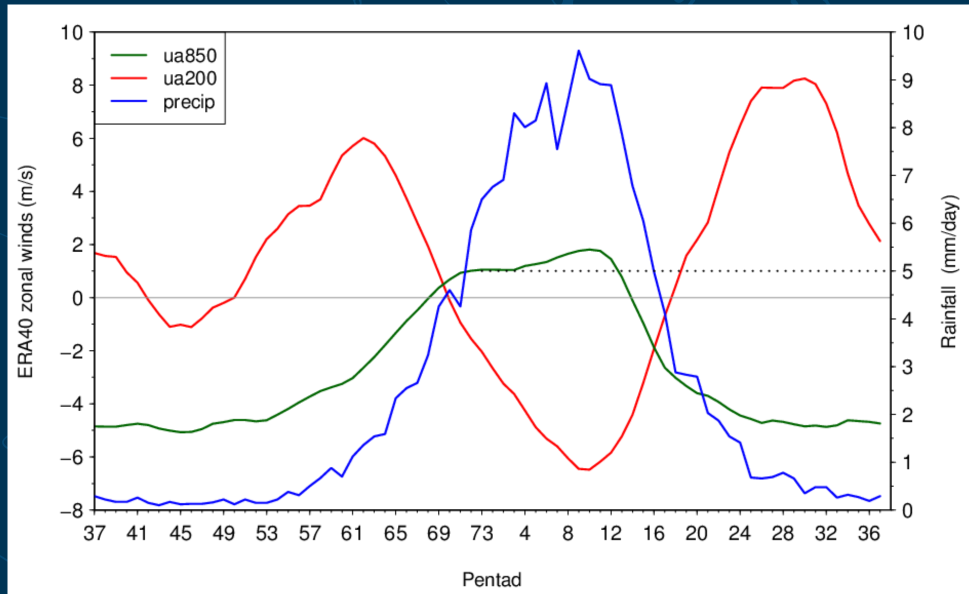
Australian Monsoon: U850; U200, PR



Annual cycle of pentad rainfall (GPCC, 1979-2010, blue line), zonal winds at 850hPa (**ERA40**, 1979-2002, green line) and 200hPa (**ERA40**, 1979-2002, red line) over tropical Australia domain (longitude=(120E,150E); latitude=(20S,0)).

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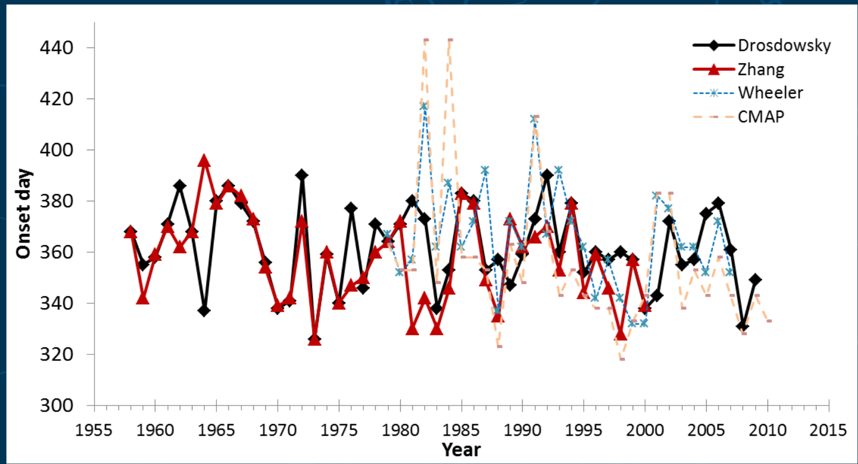
Onset dates over Darwin (12 °S)

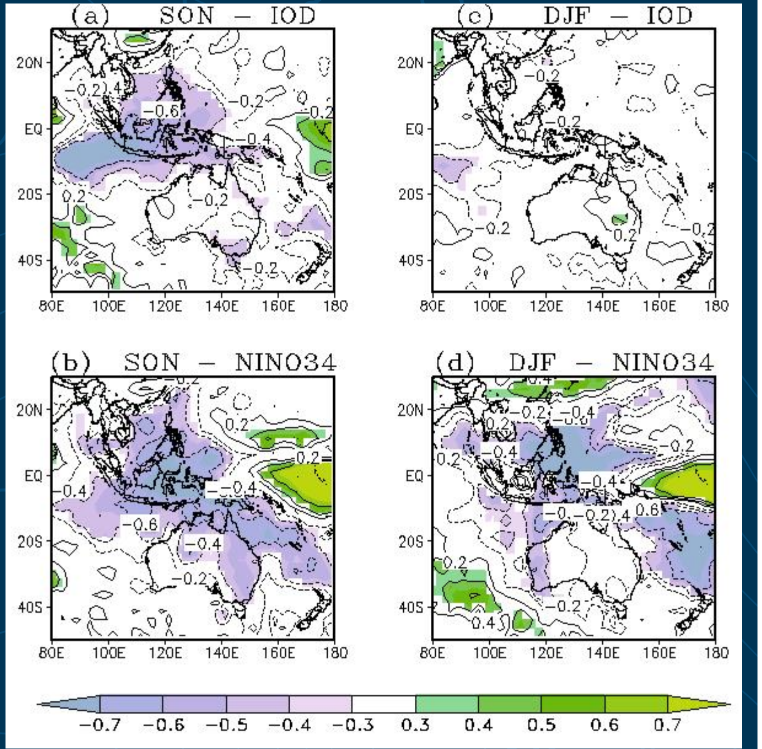
Monsoon/wet season onset dates in Darwin from four different datasets



362
358
366
357

IOD and ENSO impact on Australian monsoon rainfall

Correlations between September-October-November (SON) and December-January-February (DJF) rainfall and IOD and NINO34.



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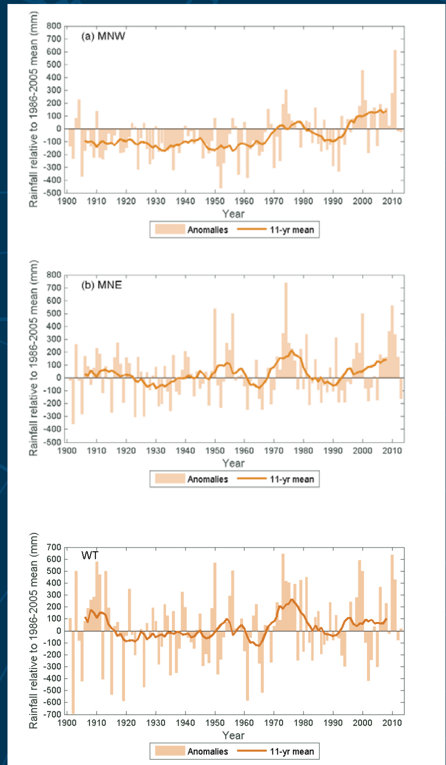
Decadal observed variability - rainfall

Observed annual rainfall anomalies (mm) for 1901-2013, compared to the baseline 1986–2005 for (top) monsoonal north west and (centre) monsoonal north east and (bottom) wet tropics



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Let's looks at model performance

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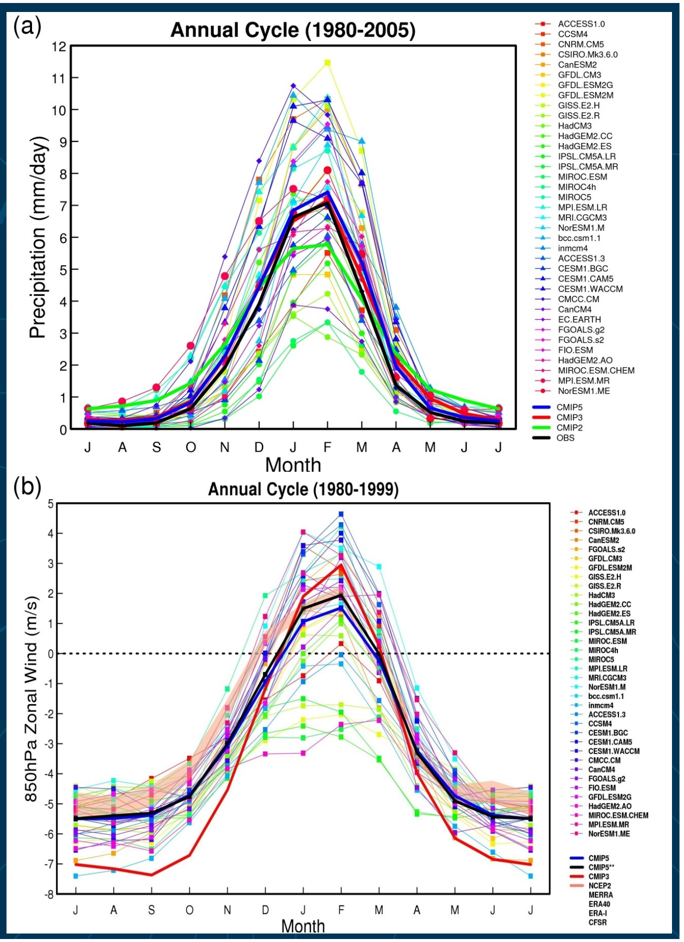
Annual Cycle

Historical (1980-2005) climatologies of:

(a) precipitation averaged over 10°S-20°S, 120°E-150°E, (land only) for CMIP5 models, CMIP5 MMM (thick red line) and CMAP and AWAP observations (thick black solid and dashed lines);

(b) 850 hPa zonal wind averaged over 5°S-15°S, 120°E-150°E for CMIP5 models, CMIP5 MMM (thick red line) and ERA40 (for 1980-2001 only) and NCEP2 observations (thick black solid and dashed lines).



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Spatial look at this discrepancy

All in one view – OBS, CMIP3, CMIP5

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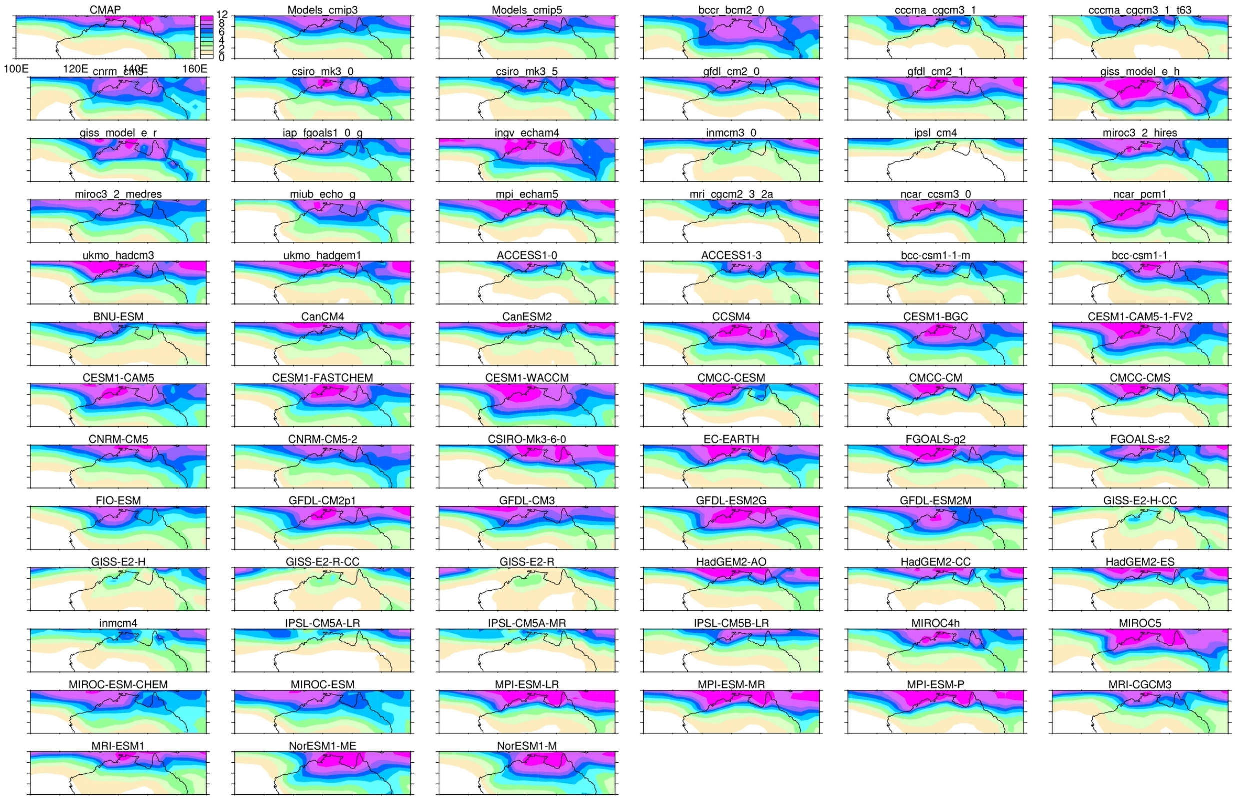
DEC-JAN-FEB (1980-1999)



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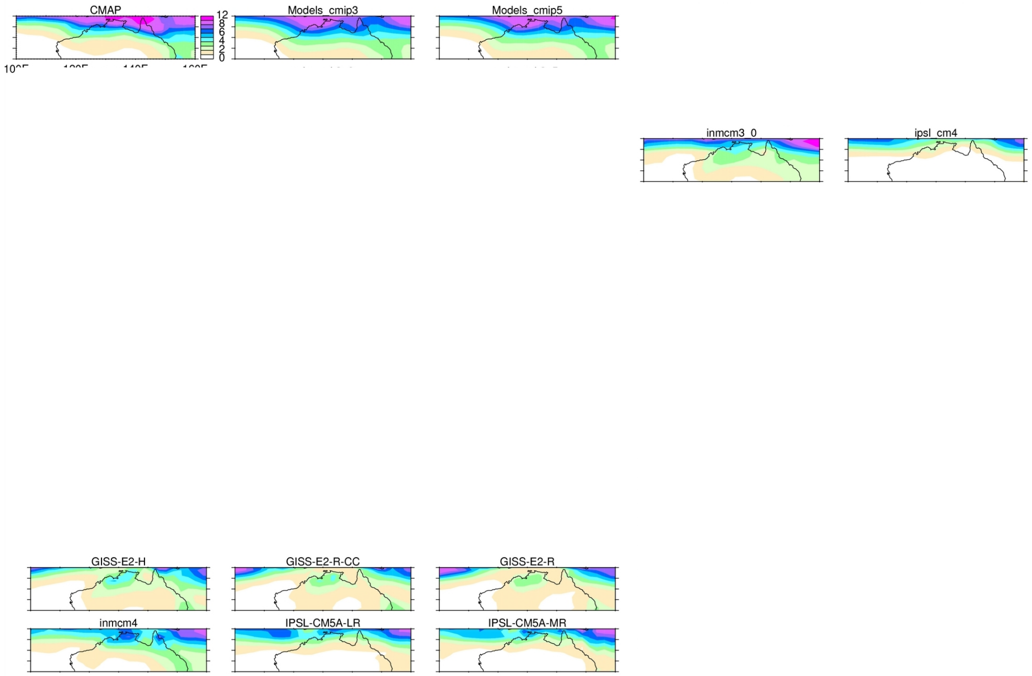
All in one view – OBS, CMIP3, CMIP5

DEC-JAN-FEB (1980-1999)



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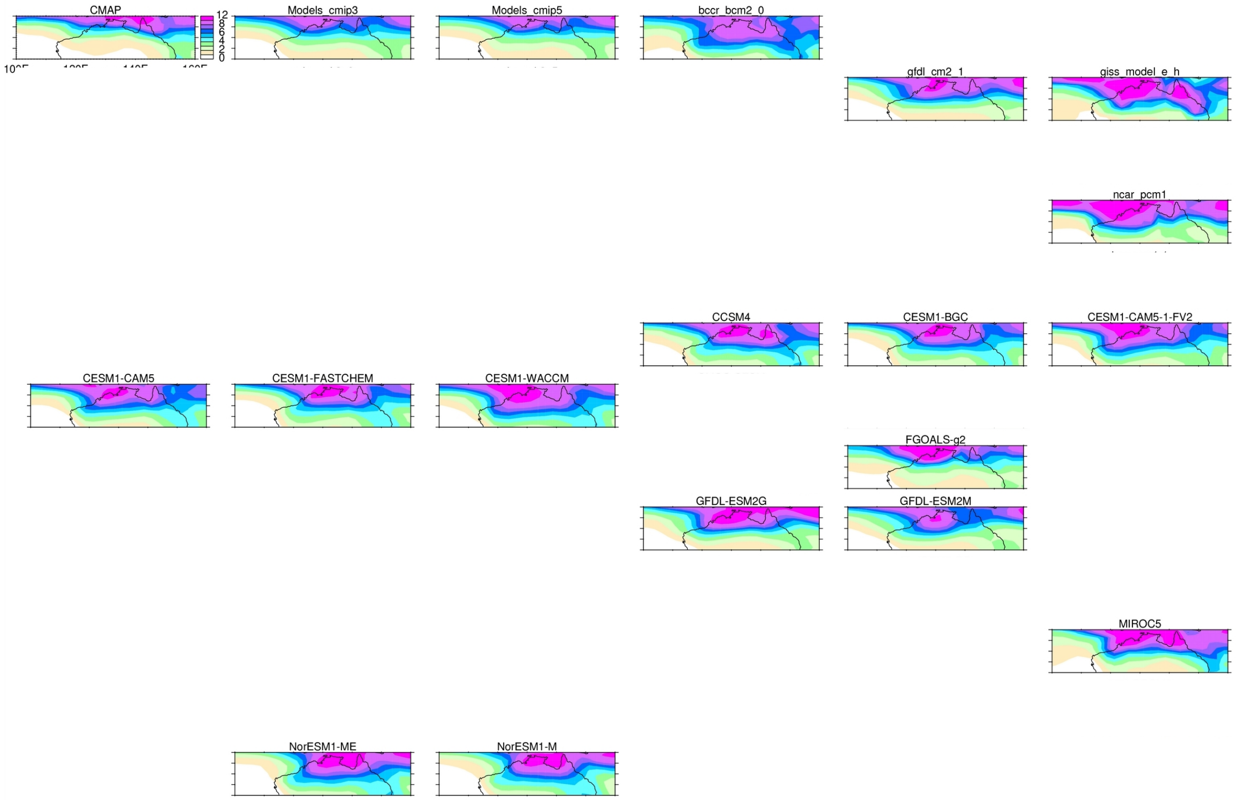
All in one view – OBS, CMIP3, CMIP5

DEC-JAN-FEB (1980-1999)



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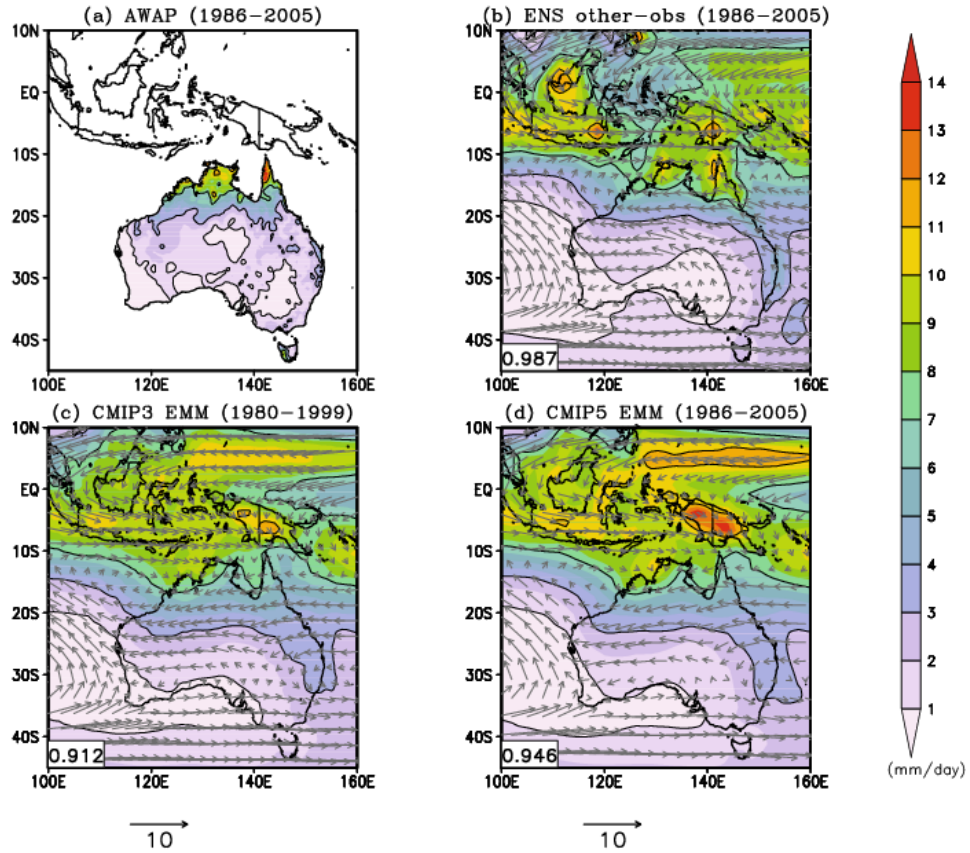

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Onset and retreat in CMIP5 models:

- using daily data from climate models
- ENSO and IOD relationship

Onset and retreat in CMIP5 models: using daily data from climate models

We use precipitable water and 850 hPa wind to capture the dynamical and moisture conditions for monsoon development in CMIP5 models

Then we assess relationship to ENSO and IOD in the models

Zhang H (2010) Diagnosing Australia-Asian monsoon onset/retreat using large-scale wind and moisture indices. Clim Dyn 35:601–618

Zhang H, Moise A, Liang P, Hanson L (2013) The response of summer monsoon onset/retreat in Sumatra–Java and tropical Australia region to global warming in CMIP3 models. Clim Dyn 40:377–399.

Zhang H, Dong G, Moise A, Colman R, Hanson L and H Ye (2015) Uncertainty in CMIP5 model-projected changes in the onset/retreat of the Australian summer monsoon. Climate Dynamics, DOI 10.1007/s00382-015-2707-x

Dong G, Zhang H, Moise A, Hanson L, Liang P and H Ye (2016) CMIP5 model-simulated onset, duration and intensity of the Asian summer monsoon in current and future climate, Clim Dyn (2016) 46:355–382, DOI 10.1007/s00382-015-2588-z.

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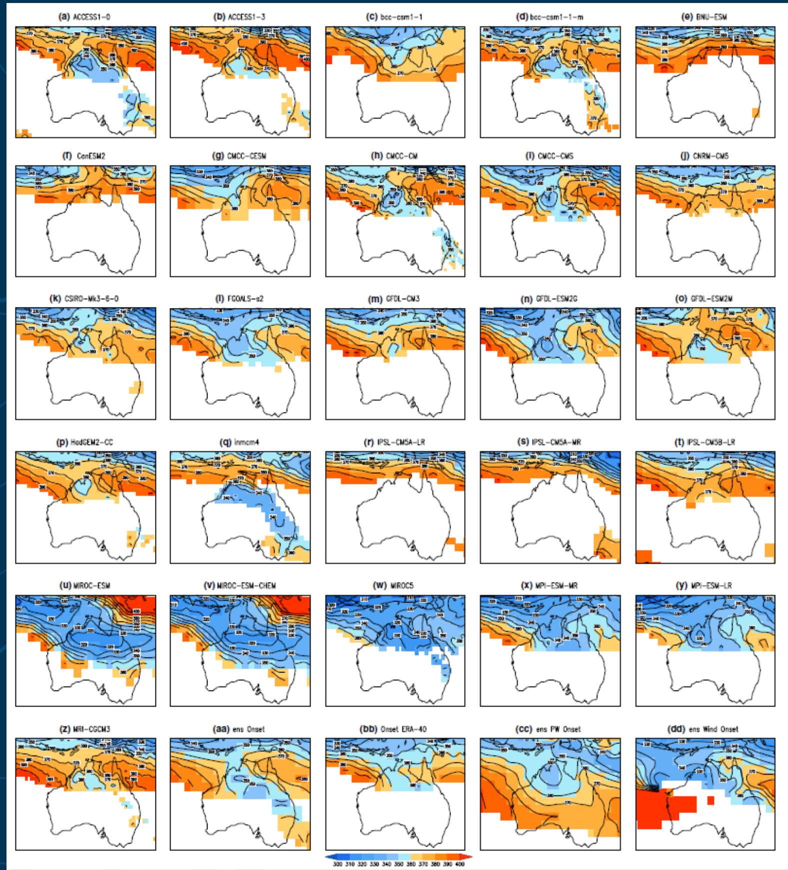
Onset



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MAYBE this….

- Firstly, the CMIP5 models do not show significant improvement in capturing observed features of the monsoon onset/retreat in the region, despite of a slightly reduced bias in multi-model ensemble results.
- We show that wind–rainfall relationship varies with models and rainfall-based wet season onsets may not adequately represent the monsoon development.
- Similar model discrepancies are seen in the modelled changes in retreat dates and further analysis re-affirms previously proposed reasons: the different influence of a number of drivers in these models.
- Overall, most of the models showed impacts of ENSO and the Indian Ocean on the Australian summer monsoon onset/retreat, but the models differed quite significantly in the magnitude of such impacts.

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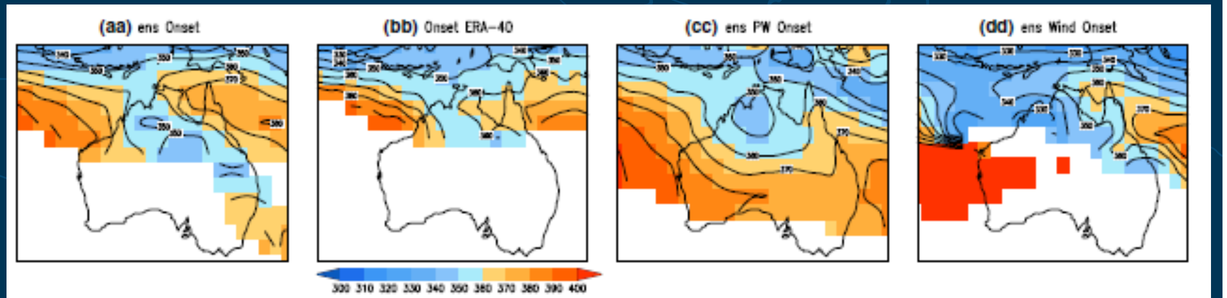
Method for onset & retreat against ERA-40

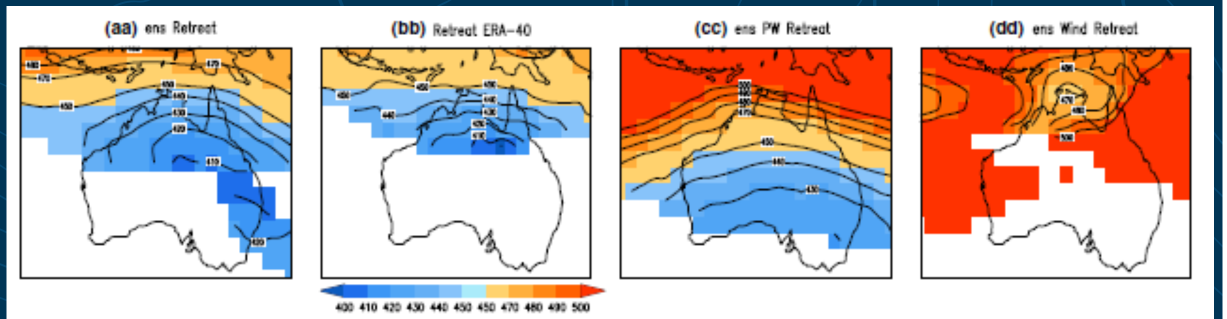


MMM
PW+U

ERA-40

MMM
PW only

MMM
U only



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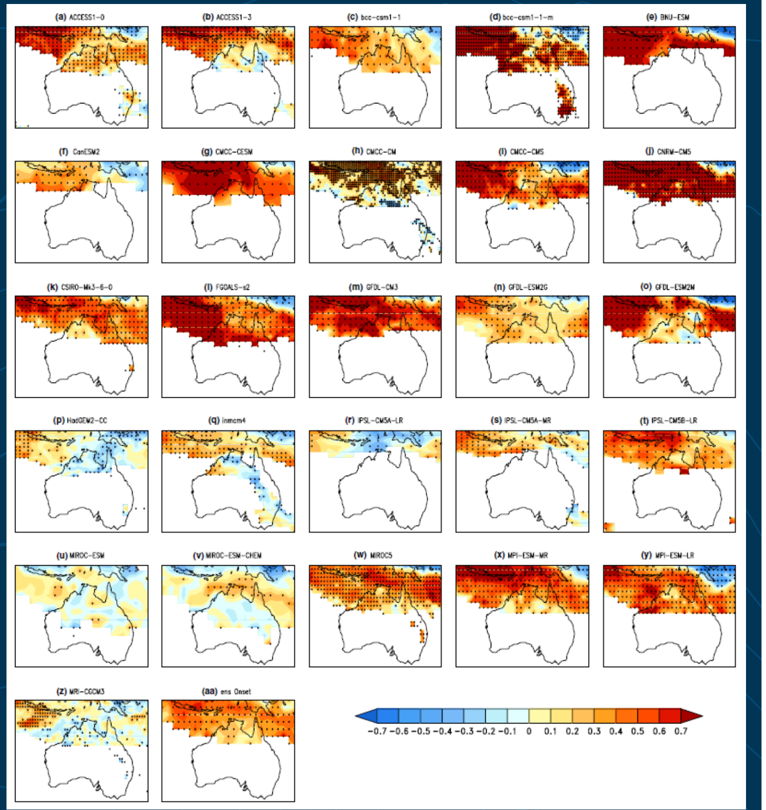
Excluding IOD

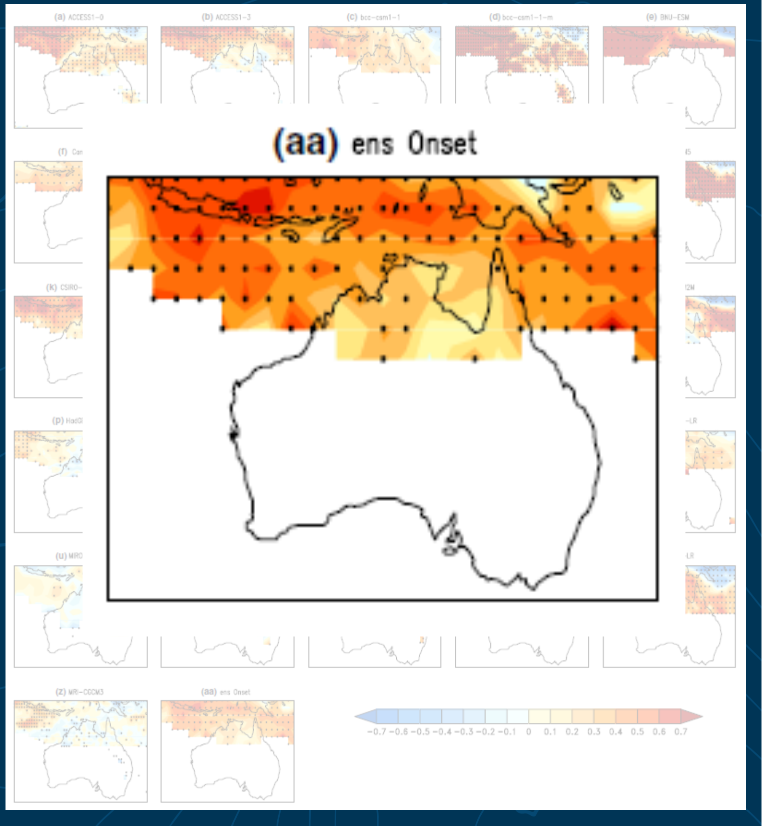
Partial Correlations of onset to ENSO



Excluding IOD – ENSO correlation

Partial Correlations of onset to ENSO (to November Nino3.4).
A majority of models show positive correlations over a large part of the monsoon domain, particularly over the adjacent waters north of the Australian continent

→ delayed onsets during El Nino years (positive Nino3.4 SST anomalies).
→ Most of such correlations are statistically significant.
→ Similar to OBS
→ But magnitude differs between models



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Reason for the model spread in ENSO response of monsoon

- In most of the models, the Nino3.4 index is highly correlated with easterly/westerly wind anomalies to the west/east of the maritime continent.
- This is largely associated with an model simulated eastward shift of the Walker circulation with high SSTs in central and eastern part of the tropical Pacific.
- Such wind anomalies are not favourable for the establishment of monsoon westerlies and thus delay its onset.
- This "cold tongue bias" (where SST is too cold along the equator and positive SST anomalies extend too far west during warming events), and a lack of persistence of SST anomalies in the central Pacific and weak ENSO magnitudes could lead to such different ENSO-monsoon relationships.

Excluding ENSO

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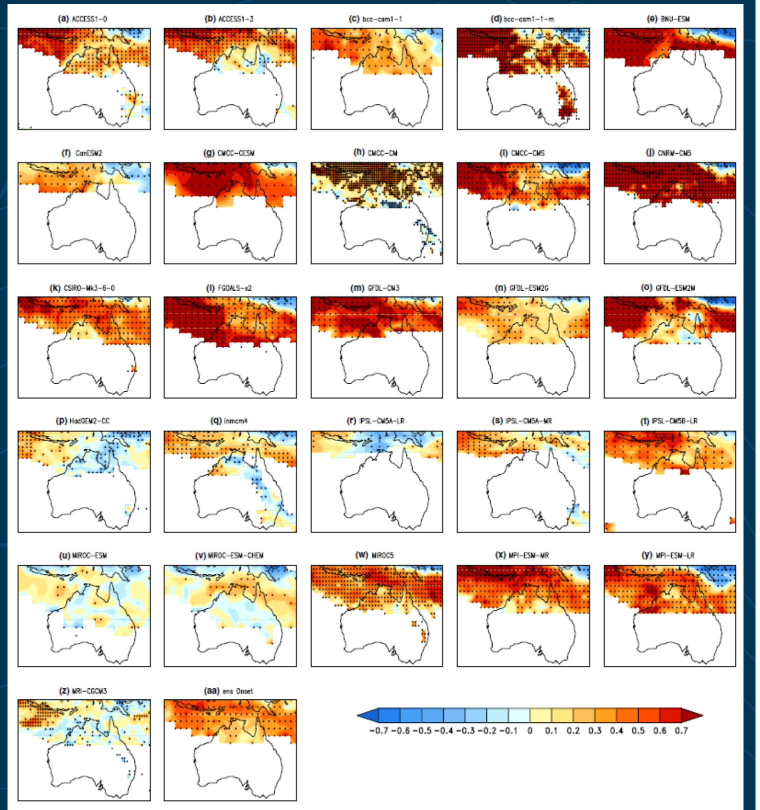
Partial Correlations of onset to IOD



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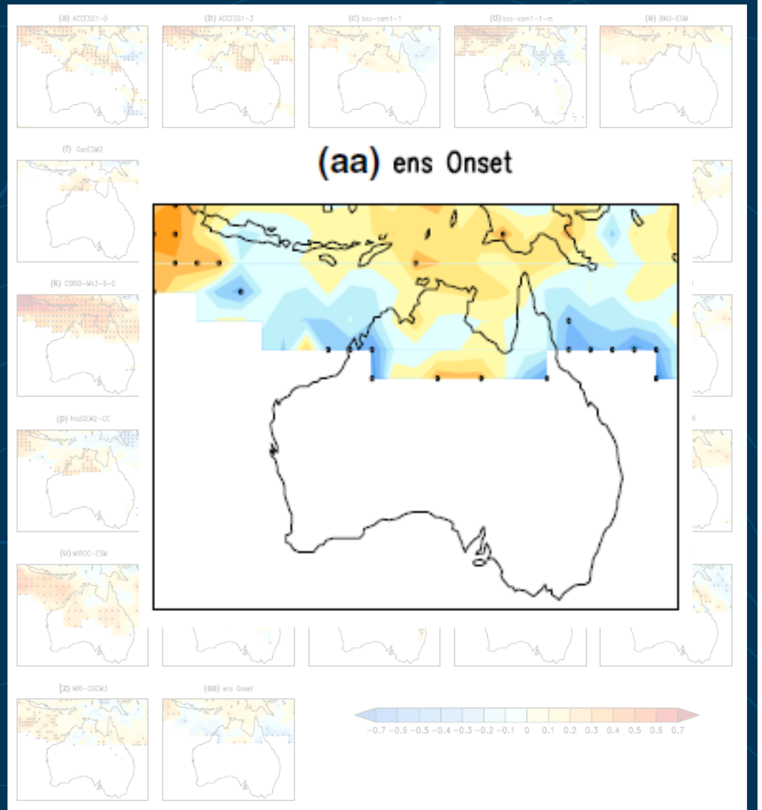
Excluding ENSO

Partial Correlations of onset to IOD

- tropical Indian Ocean SST condition can affect the monsoon onset in the tropics
- Magnitude of the correlations is generally weaker than for the Nino3.4
- relatively weak impacts on the onsets over the Australian continent : IOD itself has a strong seasonal phase lock and the IOD itself and its influence become weaker in late December / early January when the onset normally occurs in tropical Australia.



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IOD v ENSO sensitivity in CMIP5

A large part of the early (late) onset with negative (positive) IOD is through responses of regional circulation prevailing over the region:

- warmer SSTs in the eastern part of the region are linked to enhanced zonal westerly anomalies
- This favour the establishment of the summer monsoon circulation

Another feature is different combinations of Nino34 and IOD influences across the models:

- For example, in MIROC–ESM and MIROC–ESM–CHEM, the ENSO has less influence than IOD; in CSIRO-Mk3-6, FGOALS-s2 and MPI–ESM both the ENSO and IOD influences are strong; and in other models, the ENSO influence exceeding the IOD.

Possible reason for these differences:

→ related to strong/weak oceanic Rossby waves in the models.
→ The cold tongue issues as discussed earlier
→ different wind–evaporation–SST feedback in the models can contribute to such differences.

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How about the MJO?

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How about the MJO?

This work uses analysis as in Sperber & Kim (2012) to retrieve skill metric on MJO from CMIP5 models (they used CMIP3 models)

AIM:
Another example to subset the CMIP5 ensemble for rainfall projections for Australian monsoon under global warming

Observations DATA:
AVHRR OLR, (Liebmann and Smith, 1996): daily outgoing longwave radiation
GPCP, Global Precipitation Climatology Project (GPCP) daily precipitation (Huffman et al., 2001)
CMAP, pentad Climate Prediction Center Merged Analysis of Precipitation (CMAP) (Xie and Arkin, 1997)
Period: November - April 1997-2008; when MJO is typically strongest
We just need two strong EOFs onto which the model data can be projected at.

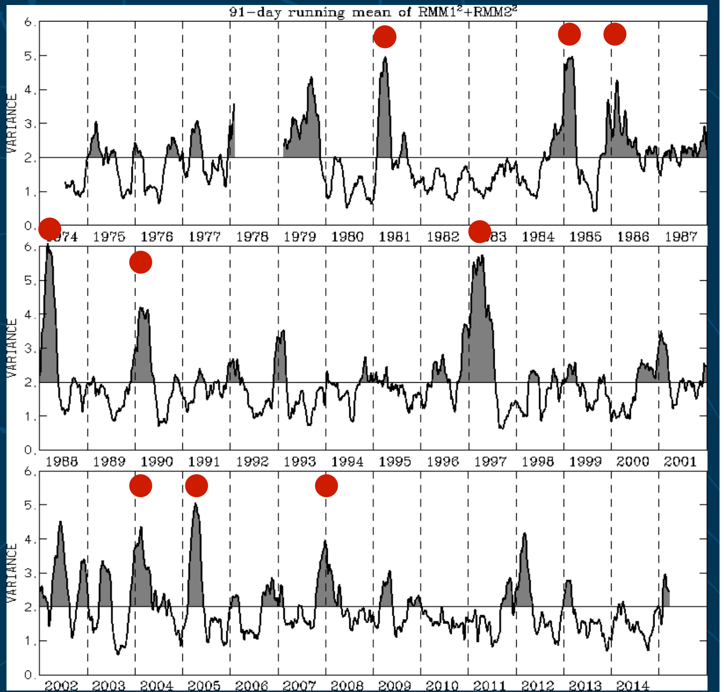
Model data:
Model OLR field, daily for period 1961-2005
Model PR field, daily for period 1961-2005

How about the MJO?

Identifying STRONGEST MJO years from Matt Wheelers figure: to produce the OBS EOF patterns.

We concentrate on the SH summer MJO, using PCs for the months November to April, when the MJO tends to be strongest (and passing through tropical Australia region), with eastward propagation of convective anomalies occurring in the near-equatorial region.

Years with strong MJO:
1980-81
1984-85
1985-86
1987-88(*)
1989-90
1996-97(**)
2003-04
2004-05
2007-08



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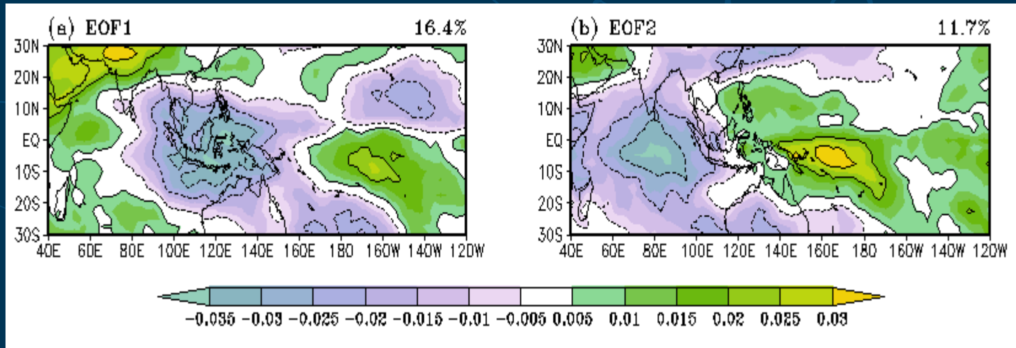
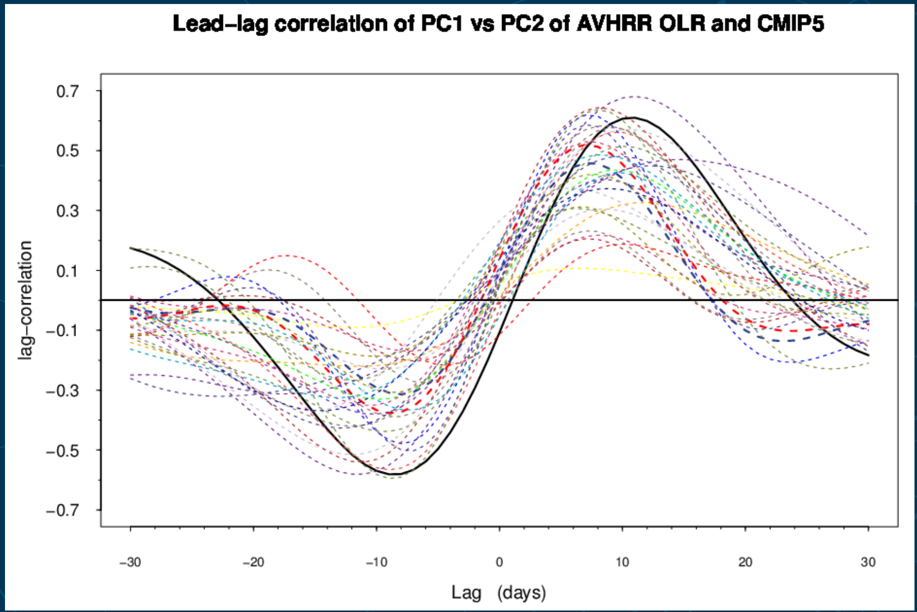
How about the MJO?



EOF patterns of 20–100 day bandpass filtered AVHRR OLR for winters of 9 strong MJO variability. (a) EOF-1 and (b) EOF-2. Positive values are shaded and negative contours are dashed.

Eastward propagation from IO (EOF2) through Maritime continent (EOF1)

How about the MJO?



Lead-lag correlation of PC-1 *versus* PC-2 over all summers (November to April) from observations (thick black line) and the 32 CMIP5 models (thin dashed lines) with positive time lags corresponding to PC-2 leading PC-1 (Indian Ocean convection leading Maritime Continent convection). The bold dashed lines (red and blue) are ACCESS1-0 and ACCESS1-3 respectively.

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How about the MJO?

Last figure shows the lag-correlation plot for the two PC time series from observations and CMIP5 models. Positive correlation for positive time lag is an indication that PC-2 leads PC-1, consistent with enhanced convection (negative OLR anomalies) propagating from the Indian Ocean to the Maritime Continent. Most of the models simulate a lag correlation structure similar to that of the AVHRR OLR (thick black line), although there are several models whose correlation structures are profoundly different from observations

First simple metrics consist of the maximum positive correlation and the time lag at which it occurs. The maximum positive correlation is a measure of how coherent and/or dominant is the propagation of convective anomalies from the Indian Ocean to the Maritime continent. The time lag is the time that it takes for the system to transition from EOF-2 to EOF-1.

From observations the maximum positive correlation is 0.63, which occurs at a time lag of 11 days.

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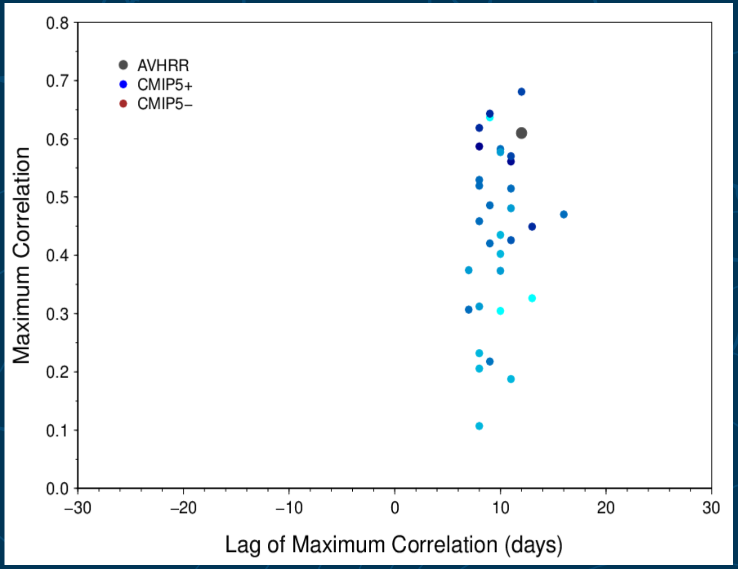
How about the MJO?

Using data from before, the maximum positive correlation and the day at which it occurs is plotted for the observations (black circles) and the 32 CMIP5 models (blue).

Deeper colour shading relates to higher model resolution.



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Frequency-wavenumber power spectrum

For the second metric the frequency-wavenumber power spectra (Hayashi, 1979) of 10N – 10S averaged GPCP and CMIP5 model daily precipitation for November to April 1997–2008 is calculated.

This level-2 diagnostic from the CLIVAR MJOWG (2009) and Kim *et al*. (2009) **shows the spectral power for eastward *versus* westward frequencies** (positive frequencies correspond to eastward propagation) for wavenumbers 0–8. **For rainfall, eastward propagating power is strongest in the 30–80 day band for wavenumbers 1–3, indicative of the MJO.**

The East/West power ratio, calculated by dividing the sum of the eastward propagating power by the westward propagating counterpart for the aforementioned MJO frequencies and wavenumbers, is a metric used to assess if eastward propagating intraseasonal variability dominates in the MJO band.

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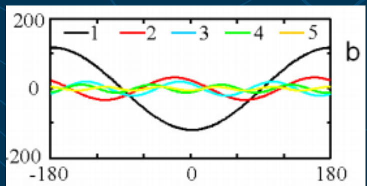
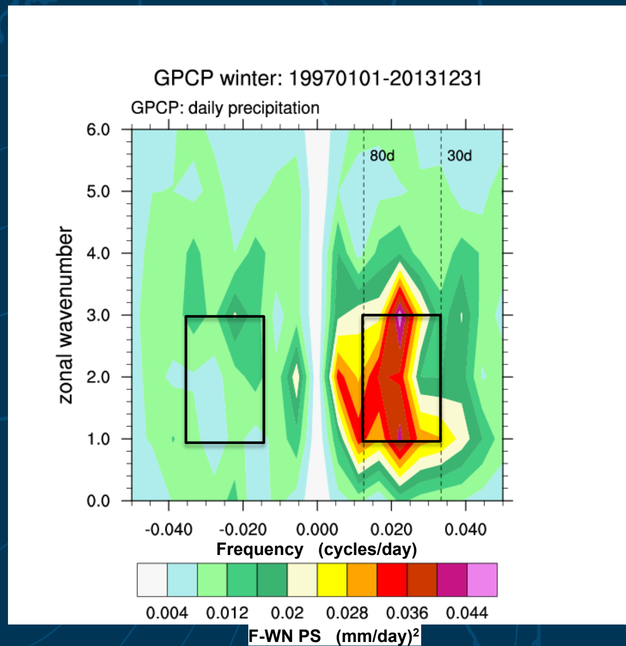
EWPR in GPCP rainfall

Second simple metrics consist of the East-West power ratio.

The power ratio is calculated for wavenumbers 1–3, and periods of 30–80 days (the boxed regions in Figure).

It is dimensionless.





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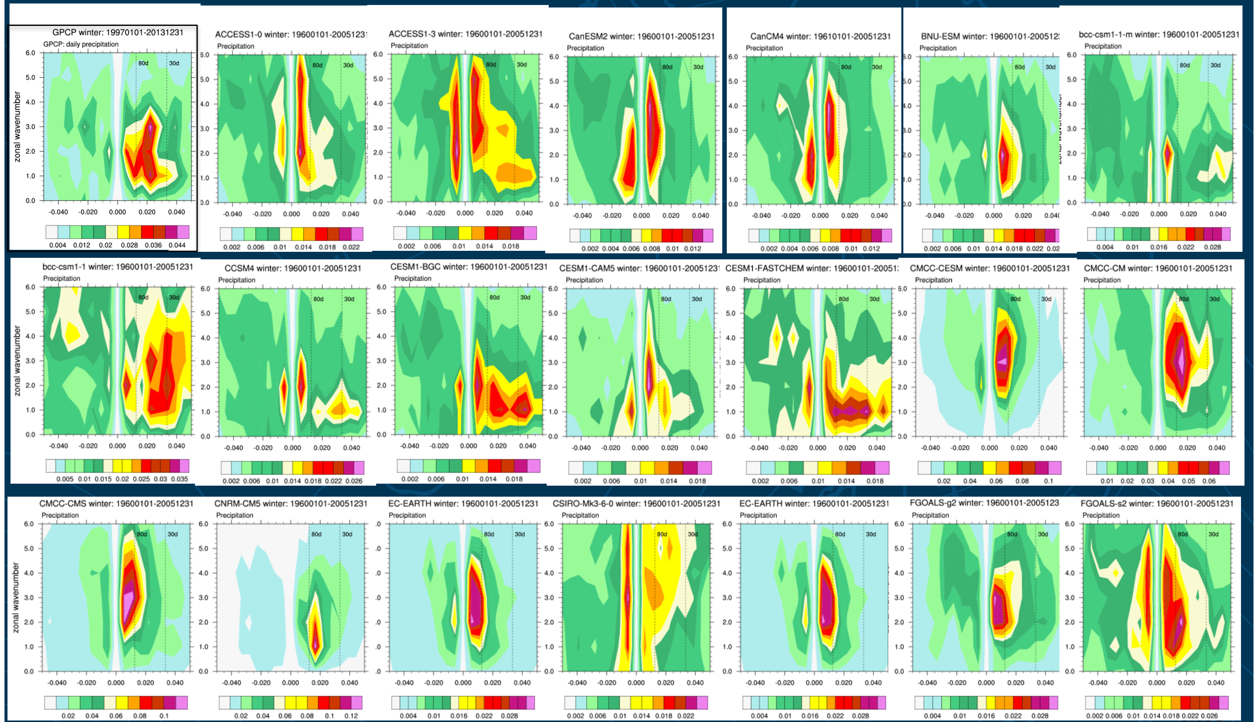
CMIP5 models



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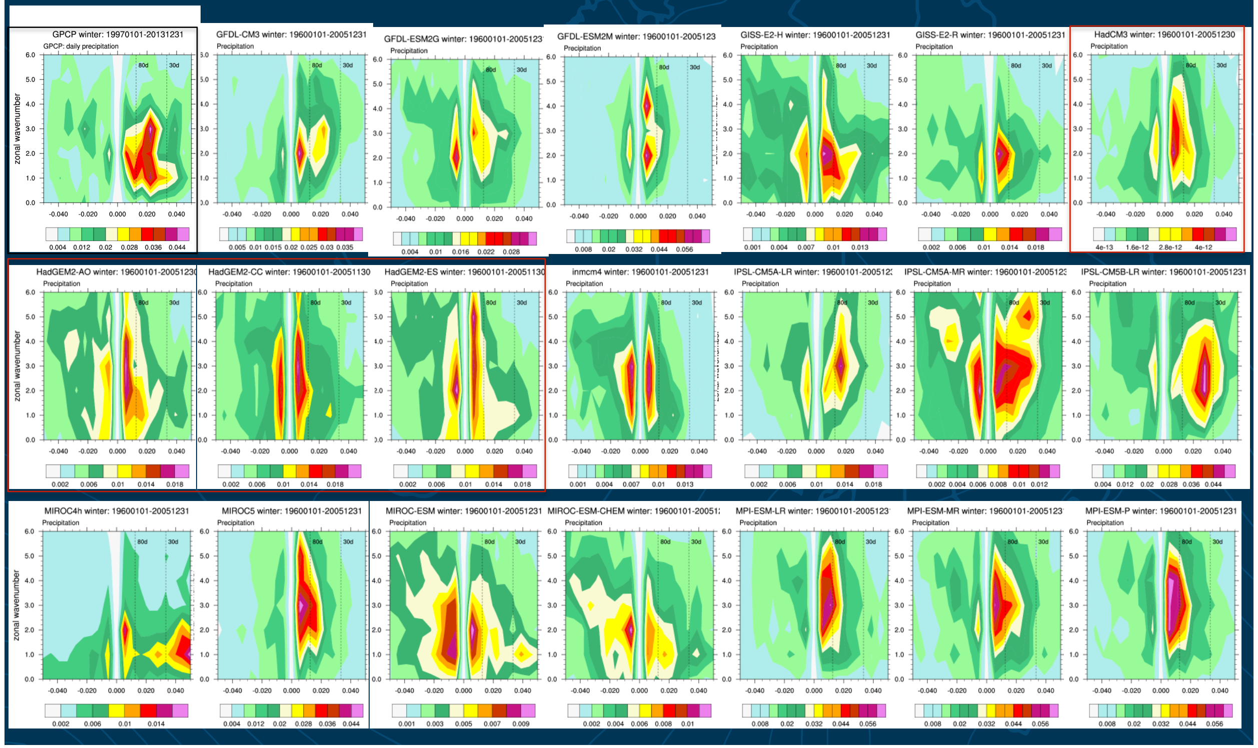
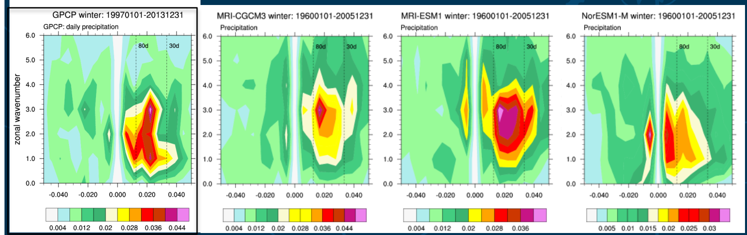
CMIP5 models



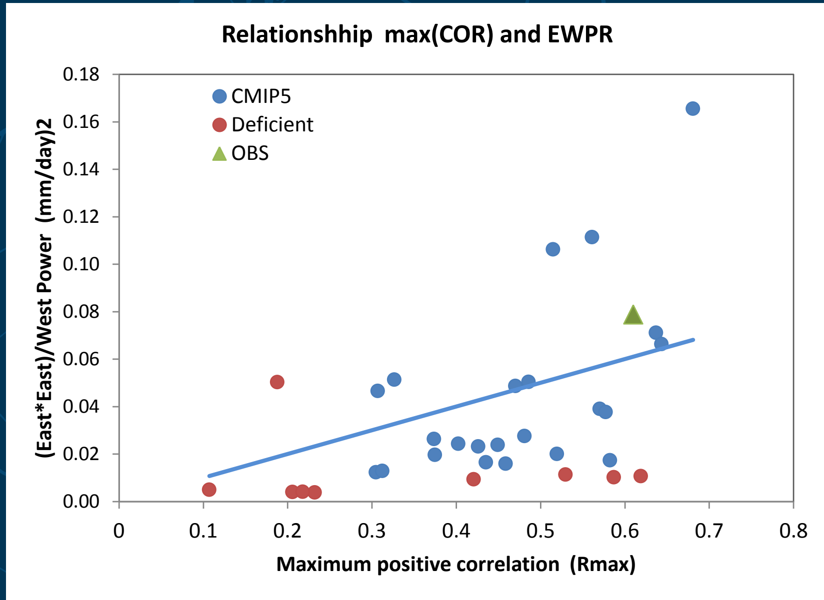
CMIP5 models



EWPR = E^2/W from boxes shown earlier

EWPR vs. Rmax in CMIP5

We can look at the subset for climate change projections of rainfall over Australia



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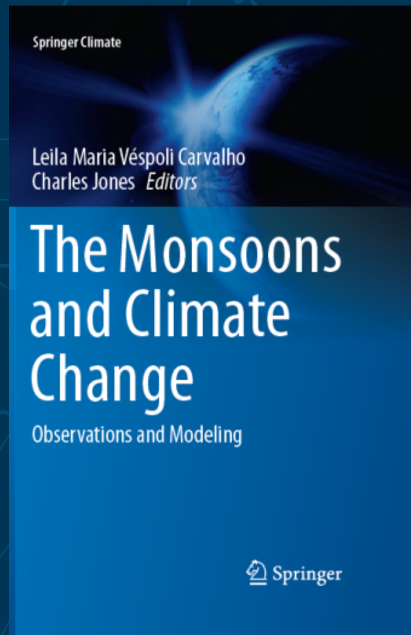
Overview

This book has now been published and includes a long chapter on the Australian monsoon:

Zhang, H. and A. F. Moise (2016) The Australian Summer Monsoon in Current and Future Climate. In: The Monsoons and Climate Change – Observations and Modeling. Eds: L. M. V. de Carvalho and C. Jones, Springer, p67-120.



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Recent improvements in ACCESS model

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Recent improvements in ACCESS model

Improving the simulation of clouds and precipitation in ACCESS

Charmaine Franklin

Why is correctly representing clouds important?

- Cloud processes influence the amount and location of precipitation
- Clouds affect the large scale circulation and climate variability
- Clouds are a key factor in determining climate sensitivity

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ACCESS errors and solutions

ERRORS	SOLUTIONS
Weak cloud radiative effect	Improved ice cloud fraction parameterisation
Too much drizzle and too little SW reflection	New warm rain parameterisations
Excessive radar reflectivities	Additional ice prognostic variable, ice sizes & heterogeneous freezing rain parameterisation
Underestimated stratiform rain areas	Increased turbulent mixing
Too little midlevel tropical cloud	Combination of changes to convection, cloud and microphysics

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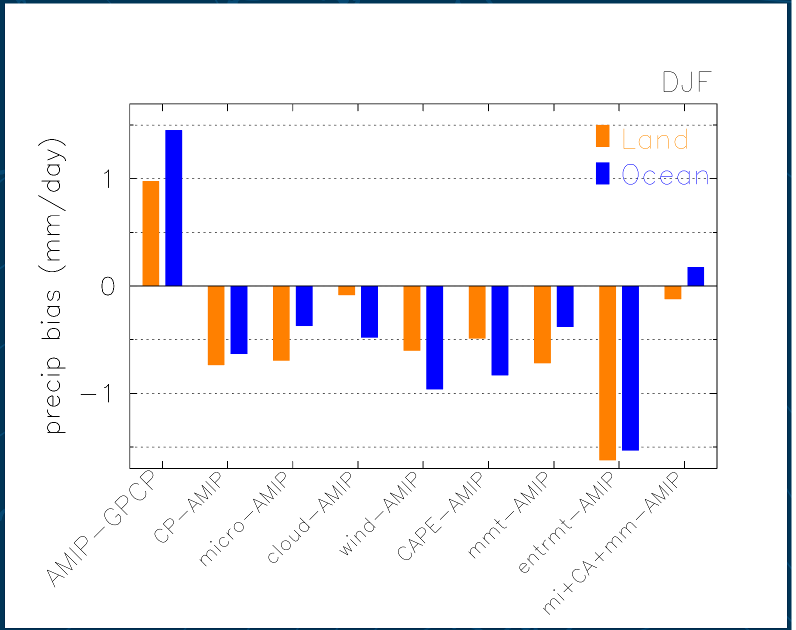
Overview

Development:

Convection scheme closure, convective momentum transports, microphysics

Increase in midlevel cloudiness not generated by individual model changes, only generated when changes are combined

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Thank you
Any questions?