Australian Monsoon in Climate Models

www.cawcr.gov.au

Aurel Moise
Bureau of Meteorology
CAWCR
Australian Monsoon: onset

Factors contributing to the Monsoon onset:

(1) land–sea thermal contrast, (pre-conditioning)
(2) barotropic instability, (additional pre-conditioning)
(3) arrival of the Madden–Julian oscillation (major trigger)
(4) intrusion of mid-latitude troughs. (often present, but only
sometimes a major trigger)

The thermal contrast due to differential heating between land and sea acts as a seasonal
preconditioning for the onset. The sensible heating over the continent leads to a reversal of
meridional temperature gradient between the Australian continent and the Arafura Sea in a layer
below 800 hPa in September–March, and sets up a thermally induced meridional–vertical
circulation which helps to transport low-level moist air inland.

The barotropic instability is often seen at 850 hPa in this region several days prior to the onset.

The sudden onset is then triggered by the arriving MJO and at times by the intrusion of a mid-
latitude trough
Australian Monsoon: non-local impacts

Onset of Australian Monsoon usually involves some "trigger": i.e. MJO or extra tropical disturbances

Case 2012/13 Monsoon: Late Onset (3-4 weeks)

Build-up of heat while Monsoon onset was late preventing moisture and clouds of tropical origin from moderating temperatures inland. Heat moved through interior towards Southern Australia and created a record heat wave over large parts of the continent.

Tasmania, most notably at Hobart, whose maximum of 41.8 °C was the highest in 120 years of records there.
GCMs:
Which aspects of the Australian Monsoon should we test for? Typically:

How well do GCM represent the mean state of rainfall during the monsoon season?
Rainfall patterns are quite complex even when evaluating longer term seasonal averages.

Mean state: DJFM rainfall climatology

Maritime Continent and tropical Australia rainfall is very difficult to simulate correctly:
- Islands
- Topography
- High diurnal rainfall variability
- Intersect of Indian and Pacific ocean impacts
And so are the low level Winds

Observed DJFM rainfall (mm/day) averaged over 2001–2010, from the satellite-based data TRMM-3B43 and 850hPa winds from ERA40.
Rainfall biases across tropical Australia and maritime continent have not improved significantly CMIP3 $\rightarrow$ CMIP5.
Rainfall biases across tropical Australia and maritime continent have not improved significantly
The spatial representation of summer precipitation climatology as measured by Taylor plot has improved CMIP3 → CMIP5 but overall still large biases.
Annual Cycle in rainfall

Large spread in model skill

Annual Cycle (1980-2005)
Australia Monsoon onset/retreat

Monsoonal Northwest - rainfall metric

Annual Total Rainfall [mm]

Intra-annual range (DJF – JJA) (mm)

A ACCESS1-0
B ACCESS1-3
C bcc-csm1-1
D CanCM4
E CanESM2
F CCSM4
G CNRM-CM5
H CSIRO-Mk3-6-0
I FGOALS-s2
J GFDL-CM3
K GFDL-ESM2G
L GFDL-ESM2M
M GISS-E2-H
N GISS-E2-R
O HadCM3
P HadGEM2-CC
Q HadGEM2-ES
R inmcm4
S IPSL-CM5A-LR
T IPSL-CM5A-MR
U IPSL-CM5B-LR
V MIROC-ESM
W MIROC-ESM-CHEM
X MIROC4h
Y MIROC5
Z MPI-ESM-LR
a MPI-ESM-P
b MRI-CGCM3
c NorESM1-M
d NorESM1-ME
Teleconnection to ENSO

On inter-annual time scales Australia wet season rainfall is modulated by ENSO

ENSO representation in GCMs impacts on Australian rainfall

PLOT: STD(PR) vs STD(SST-nino34)
Impact of drivers on seasonal rainfall

Drivers and regional detail → Risbey et al. 2009

Dec - Feb
Jan - Feb
Mar - May
Jun - Aug
Sep - Nov

Blocking
SAM
IOD
ENSO

1957-2006
Correlation between NINO3.4 SSTs and monthly anomalies of rainfall for CMIP5 models (1980-2005).
Pattern correlation between the CMAP observed and model correlation patterns for the CMIP3 (green bars) and CMIP5 (red bars) models.
CMIP5 vs AMIP – does this improve bias?

- Cold tongue bias in Pacific seems to improve which improves rainfall along equatorial Pacific.
- Eastern Indian ocean biases increased strongly, including maritime continent and northern Australia.
Some words about future changes

% change in precipitation (5% intervals) for rcp8.5, DJF average (2080-99), n=40
Projected changes – land only

Large model spread

"High confidence in little change"

Note: recent observed increases not captured
Projected changes – region

Result in the **mean precipitation changes** can be separated into changes driven by circulation changes and by thermodynamic changes – in the case of Australian region these are opposing each other.
Monsoon shear line (from monthly data)

Zero contour of 850 hPa westerly winds ("monsoon shear line"): 

NCEP2 (blue dashed line)  
CMIP5 HIST (1980-1999) MMM (black solid line)  
RCP8.5 (2080-2099) MMM (red solid line)

→ Little change
Changes to variability: seasonal

Seasonal Changes in PDF of precip variability
RCP8.5
HISTORICAL

Change in DJFM rainfall variability in tropical AUS box

Change in STD of DJFM rainfall, RCP8.5
CHANGES to sub-seasonal variability

Time series of sub-seasonal standard deviation of tropical Australian summer (DJFM) monsoon rainfall for 25 CMIP5 models for RCP8.5 scenario. The variability ($\sigma$) is computed as the root-mean-square of the daily deviation from the seasonal mean of each individual year. The running mean is shown in red and the percentages show the relative change in standard deviation in the future with respect to the past: $(\sigma_{2071-2100} - \sigma_{1871-1900}) / \sigma_{1871-1900}$.

~15% increase
Summary

- Simulating the monsoon better is not just beneficial in tropical regions.
- The Maritime continent and Australian monsoon regions is a complicated beast to simulate.
- BIAS: still problems in rainfall biases across maritime continent and northern Australia ("problem region" for GCM's rainfall simulation)
- Large model spread in performance in simulating rainfall in this region.
- Teleconnection patterns to ENSO have improved CMIP3→CMIP5 but there are still a large number of models deficient.
- AMIP improves things mainly in the Western Pacific (i.e. improves the cold tongue bias), but large fraction of rainfall biases in MC and AM are non-SST related (directly).
So what is incorrect/missing in GCMs?

Adequate representation of crucial process:
- Diurnal cycle of precipitation – especially in this region
- Convective regimes: model vary greatly in the representation of different regimes
- MJO → see tomorrow
- ENSO → a crucial ingredient in this region
- (tropical cyclones)?
- Large scale circulation: SH circulation is not as well simulated as the NH (role of southern ocean clouds in tropical rainfall biases)
What did we find in APRIL 2013 at the WGNE Systematic Modelling Errors Workshop?
CONCLUSIONS from "Parameterization of convection and its impact on the representation of tropical climate features" - by Catherine Rio, WGNE Workshop

The strategy:
Improve the representation of physical convective and cloud processes to reduce biases and increase our confidence in climate simulations.
➔ Fruitful strategy: diurnal cycle of convection, low-level clouds...
➔ Not always sufficient to decrease mean biases

Important to **consider coupled processes** (land surface, ocean, radiation, ...)
➔ Importance to discuss and understand more the role of tuning
➔ Modifies precipitation variability from the diurnal to the intra-seasonal scale
➔ Modifies the climate sensitivity
➔ Sensitivity of convection to tropospheric humidity
➔ The mesoscale organization of convection
➔ Stochasticity
Workshop Summary Report

From Tropical Session:
…concluded that long-standing systematic errors in the tropics in weather and climate models remain large and that there has been relatively little progress in reducing them despite some modest progress in parameterisation development. While new analysis techniques are shedding more light on the model errors, the representation of convection and its associated cloud and precipitation fields remain poor, even in the mean state.

Recommendations:
(1) …new ideas for the representation of convection in global models. A special focus area should be the representation of organized convection.

(2) Better connect the research on physical processes in the tropics with those on tropical dynamics, … a first step could be a workshop on the physical interpretation of model errors, model evaluation and development in the tropics.

Should/Is CLIVAR AAMP involved?
Where to next?

More experiments
More model development
Better integration of different groups (developers, analysers, evaluators)
Better integration of different time scales
Step away from EMM and focus on single models to understand processes

Underway/Plans in Australia:
1. ACCESS model experiments to investigate the role of land-air interactions on Australian monsoon, especially in the build up season (CAWCR)
2. ACCESS model experiments to investigate the role of land-surface representations on Australian monsoon (CAWCR).
3. ACCESS experiments to investigate diurnal cycle of rainfall (CoE CSS)
4. ACCESS experiments to focus in maritime continent (from NWP to Climate)
5. Establish focus on improving convection in model (CAWCR and CoE)
Aurel Moise

Email: a.moise@bom.gov.au
Web: www.cawcr.gov.au

Thank you