

Personal Introduction

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Research Interests

- Australian seasonal climate and associated large-scale oceanic and atmospheric circulations

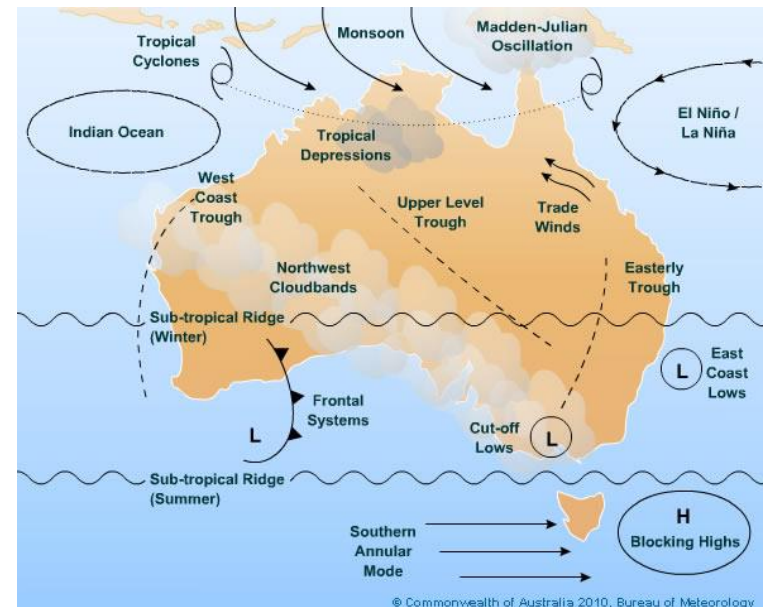
e.g. El Niño & Southern Oscillation

Indian Ocean Dipole (IOD)

Southern Annular Mode (SAM)

to understand the predictability of Australian climate

- Evaluation of forecast skill



Australian Government

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Introduction of S2S forecast and understanding the prediction system

- **Overview of sources of predictability of S2S climate**
- **Dynamical S2S climate forecast activities in Australia: POAMA/ACCESS-S**
 - configuration
 - forecast products
 - data availability



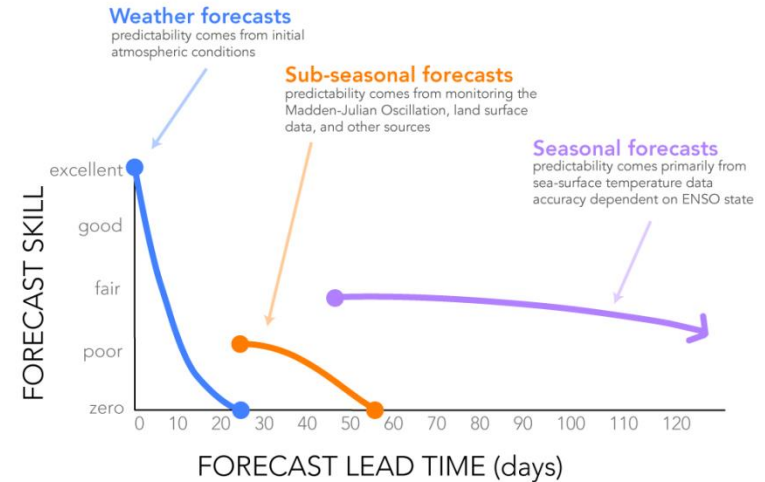
Sub-seasonal 2 Seasonal climate forecasts



Time scale: ~2 weeks up to a season

A weather/climate process is predictable over a time scale roughly equal to it's lifetime (i.e. time scale of lifespan ~ maximum level of predictability)

- Thunderstorm: a few hours
- Synoptic weather system: a few days
- Arctic Oscillation (AO)/North Atlantic Oscillation (NAO)/Southern Annular Mode: a few weeks
- Madden-Julian Oscillation (MJO): 1-3 months
- Monsoons: 1-2 months
- Indian Ocean Dipole mode : up to 3 month
- El Nino and the Southern Oscillation: up to a year



Infographic taken from <http://iri.columbia.edu/news/qa-subseasonal-prediction-project/>

If your regional climate (e.g. T, rainfall) is strongly influenced by these large-scale climate phenomena, it may be predicted with some useful skill in S2S time scales

Major sources of predictability of S2S climate



- **Ocean-Atmosphere coupling is one of the key processes for S2S climate prediction**

Atmosphere drives upper ocean circulations and feeds heat, momentum & moisture to the ocean surface

- outside of tropics, SSTs are too cold to influence atmosphere
- in the tropics, SSTs are warm enough to trigger deep convections, and therefore, change atmospheric dynamics

Because ocean changes slowly, tropical SSTs control the mean behaviour (i.e. low frequency variability) of atmosphere → source of predictability of S2S climate

- **High predictability of atmospheric temperature and rainfall**
 - across the tropical ocean basins (especially over the tropical Pacific due to El Nino/La Nina)
 - along the paths of stationary Rossby waves (i.e. teleconnection) – deep convections over the tropical warm-pool excite equivalent barotropic Rossby waves propagating toward the NH/SH high latitudes & Rossby wave activity is strongly influenced by ENSO, IOD and MJO



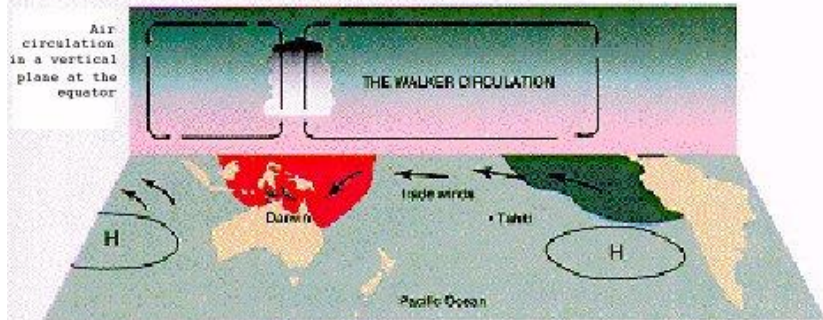
Important modes of the tropical SST variability



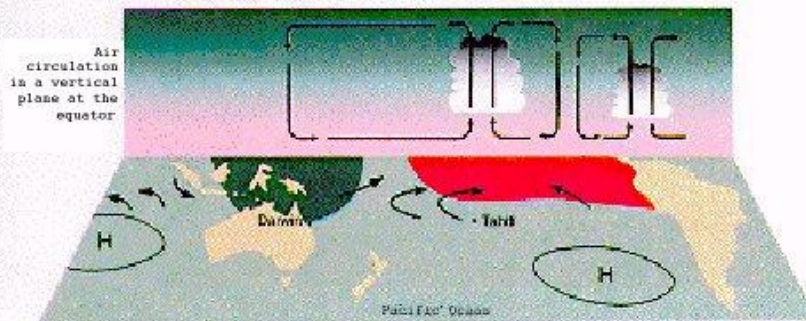
El Niño-the Southern Oscillation (ENSO)



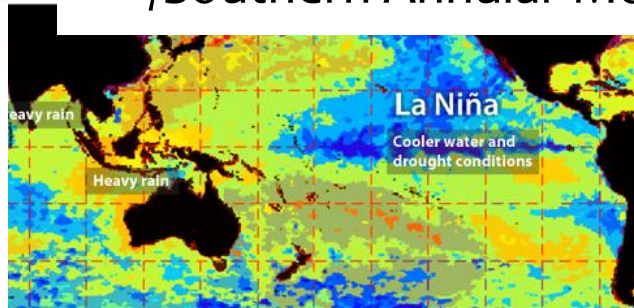
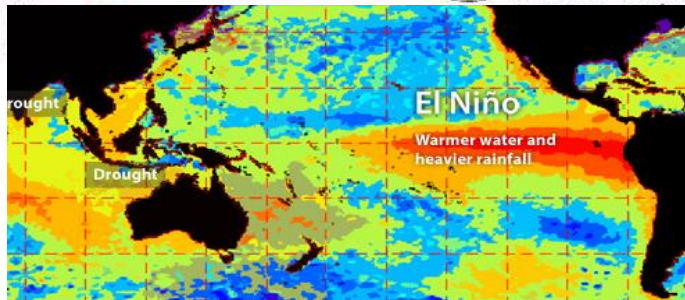
Typical Walker circulation pattern



Walker circulation during an El Niño

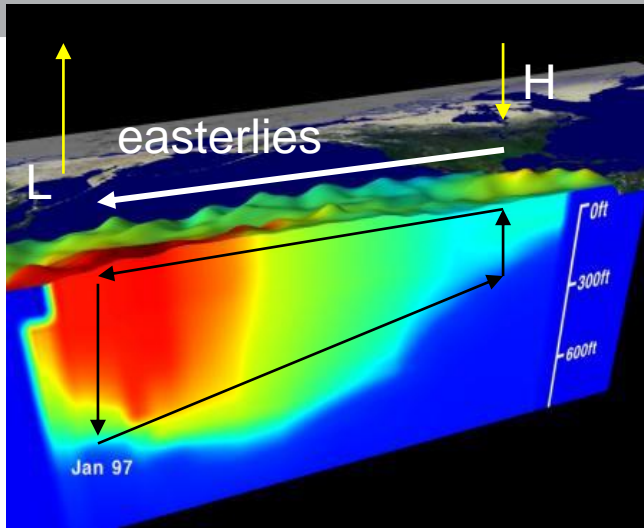


■ warmer sea ■ cooler sea H typical summer positions of high winds



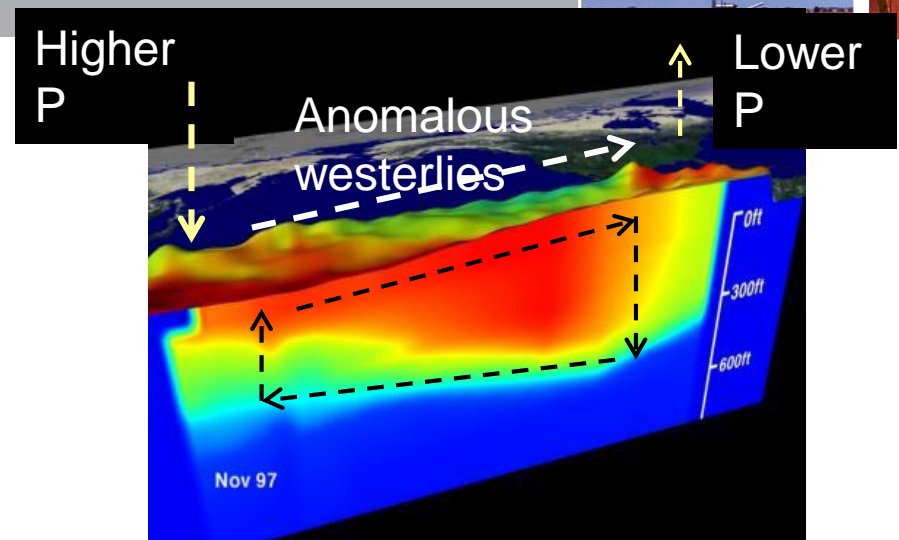
- Explains ~30-40% of the total variance of tropical SSTs in monthly – seasonal time scales
- One of the most important drivers of extreme climate events in subseasonal time scale
- Directly impacts regional climate over the Pacific Islands & Pacific rim countries
- Indirectly impacts regional climate outside of the tropical Pacific by promoting certain phases of AO/NAO/Sudden stratospheric warming /Southern Annular Mode

Normal condition



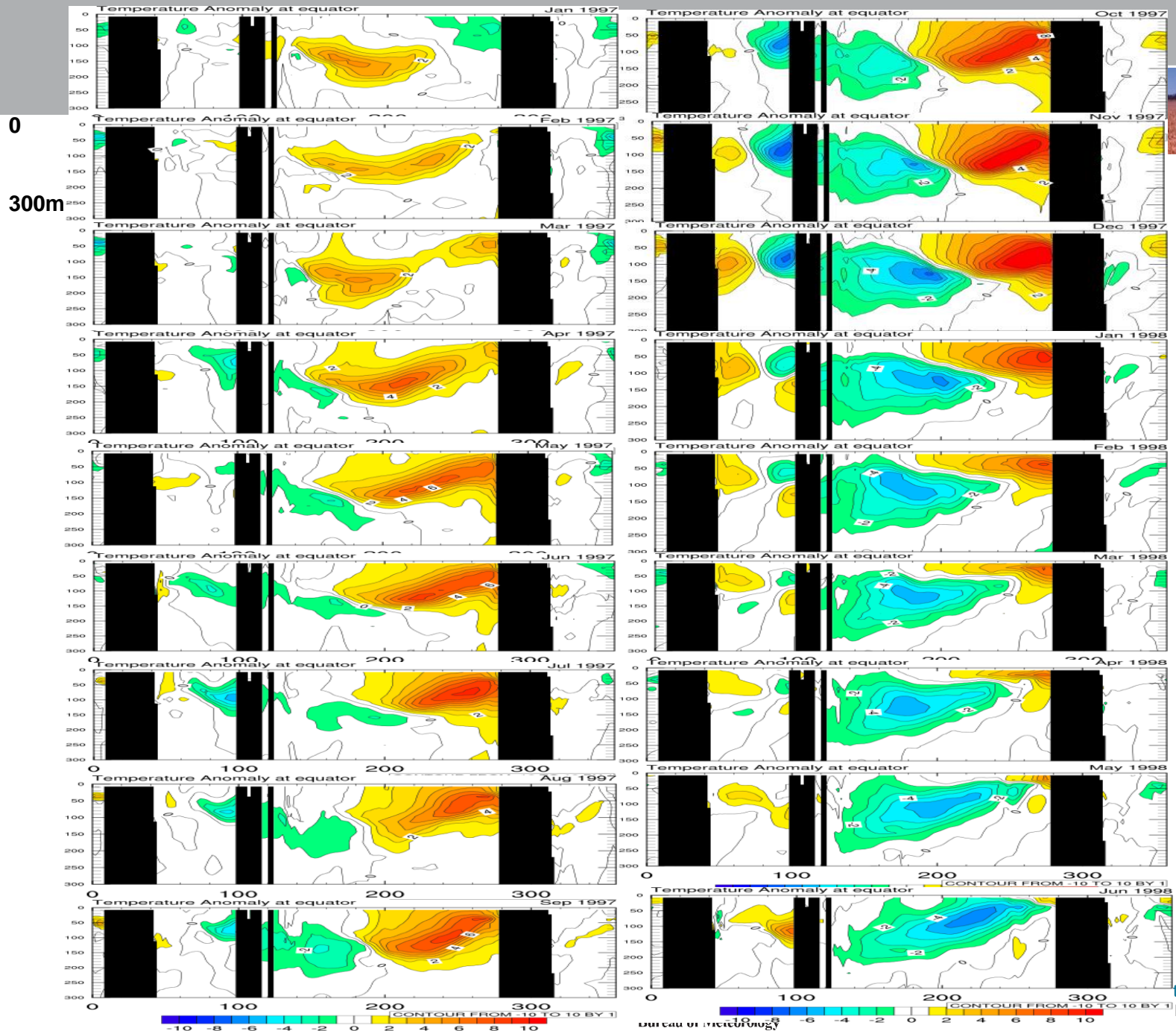
- Easterlies
 - westward surface current
 - upwelling of cold water in the east and along the equator
 - shallow thermocline in the east/ higher SSTs & deeper thermocline in the west
 - eastward undercurrent

EI NINO



- Easterlies break down
 - reduce upwelling
 - deeper thermocline/ higher SSTs/ lower pressure in the east
 - reduce the zonal gradients of SST & pressure
 - **reduce the easterlies**
- (+ve Bjerknes feedback; Bjerknes 1969)

One of the causes for the break down of easterlies is westerly wind bursts in the western-central Pacific (e.g. related to strong MJO activity)



Ocean
Subsurface
anomalies in
1997-1998
El Nino to La
Nina

← taken
from
POAMA
experimenta
l website
ocean
monitoring
page

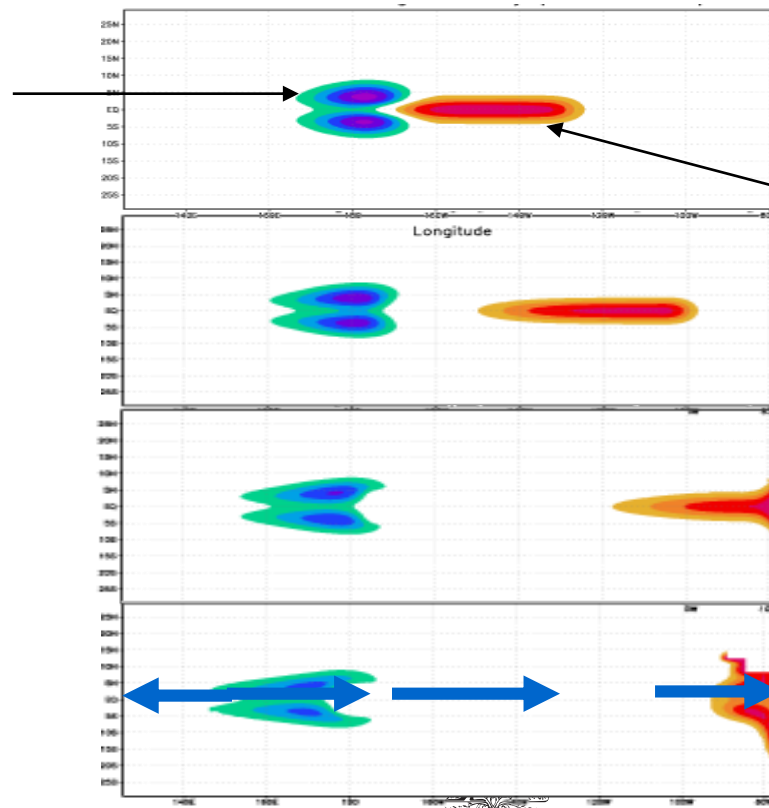
- Ocean subsurface dynamics

Westerly Wind Bursts in the western/central Pacific excite equatorial oceanic downwelling Kelvin waves & off equatorial oceanic upwelling Rossby waves

→ Without this subsurface wave dynamics, ENSO will not fully develop

→ Ocean subsurface wave dynamics gives predictability to the evolution and decay of ENSO

Ocean surface height anomaly



Off-equatorial oceanic Rossby wave (travelling ~ 1/3 speed of Eq. Kelvin wave)

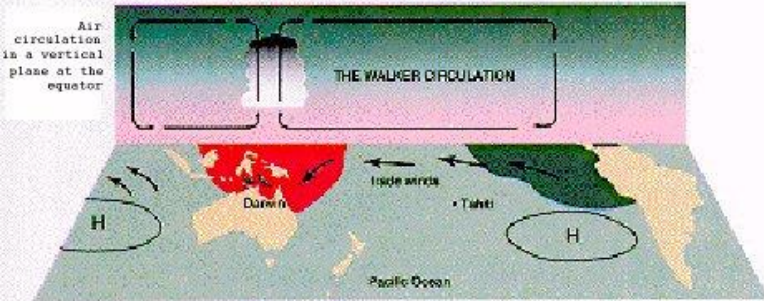
Equatorial oceanic Kelvin wave (with speed of 2-3 m/s)

Termination of El nino / onset of La nina

Global Impact of El Nino

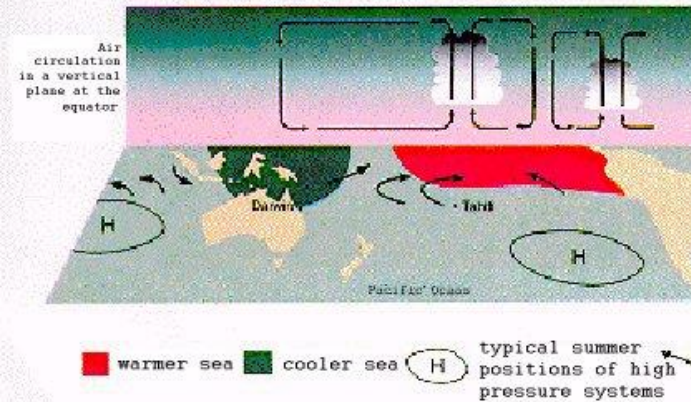


Typical Walker circulation pattern

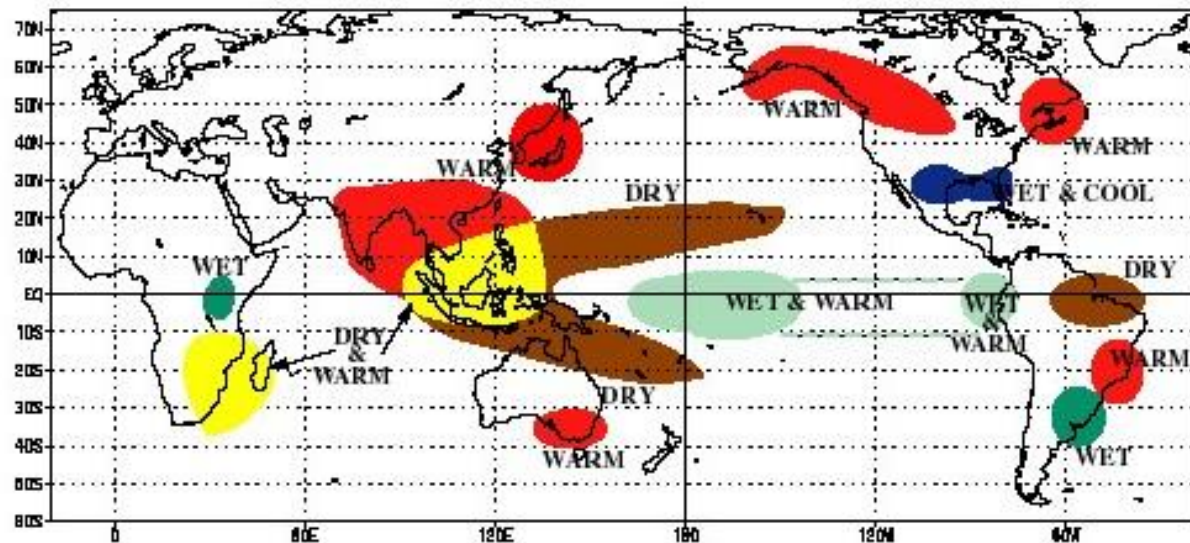


Once El Nino is manifested at the surface, it changes the location and intensity of deep convections over the tropical Indo-Pacific region, thereby significantly affecting the global atmosphere

Walker circulation during an El Nino

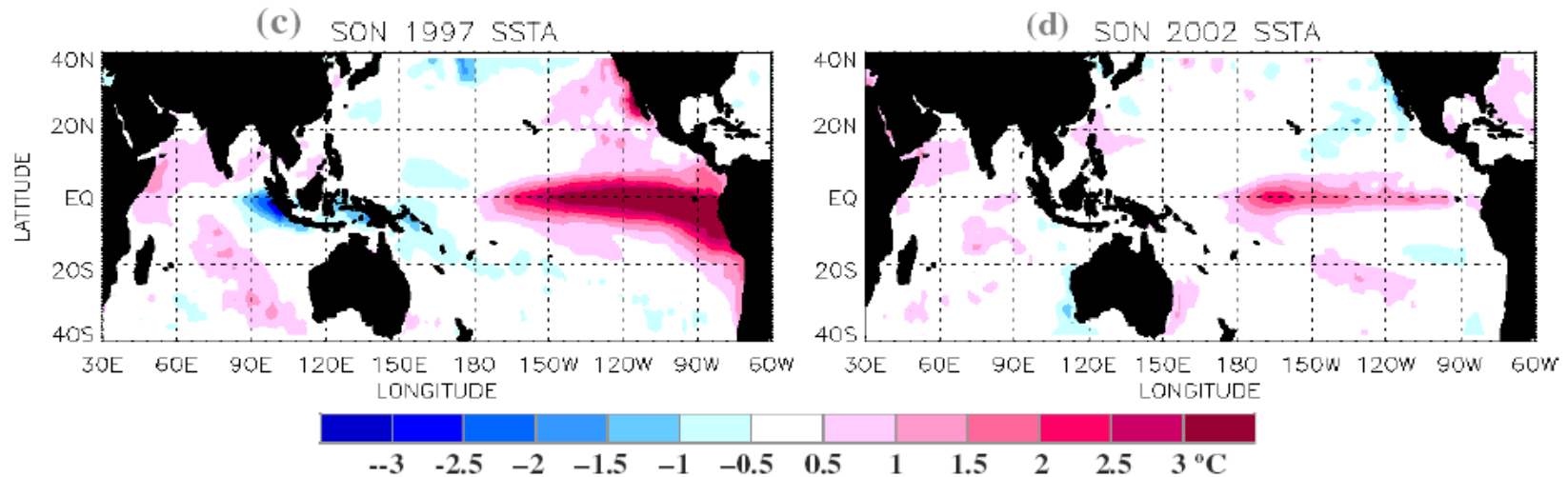


WARM EPISODE RELATIONSHIPS DECEMBER - FEBRUARY



Different flavors of El Nino

Eastern Pacific type vs Central Pacific type



taken from Wang and Hendon (2007)

- Australian rainfall (e.g. Wang and Hendon 2007)
- Indian monsoon (e.g. Kumar et al. 2006)
- North eastern Asian and North American summer rainfall (e.g. Weng et al. 2007; Karori et al. 2013)
- North Atlantic Hurricane (Kim et al. 2009)

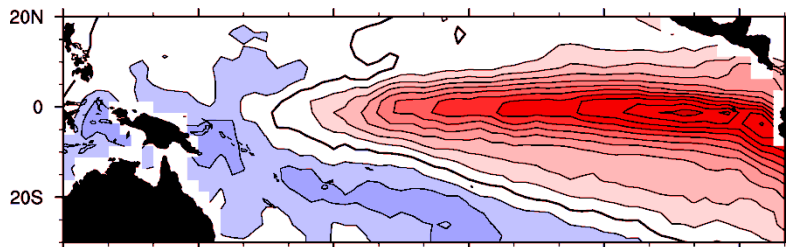
Not only the occurrence of El Nino, but also the spatial details of SST anomalies during El Nino are important for regional climate

Different flavors of El Nino

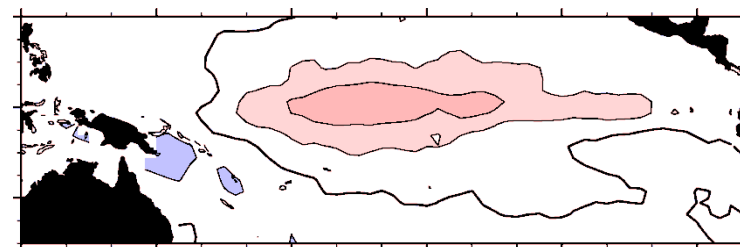
Eastern Pacific type vs Central Pacific type



Eastern Pacific type



Central Pacific type



NINO3 index

1st leading EOF mode of
tropical Pacific SST anomalies

NINO4 index relative to NINO3 index

2nd leading EOF mode of tropical
Pacific SST anomalies

El Niño Modoki Index (Ashok et al.
2007)

La Niña doesn't have a clear distinction between EP type
vs CP type



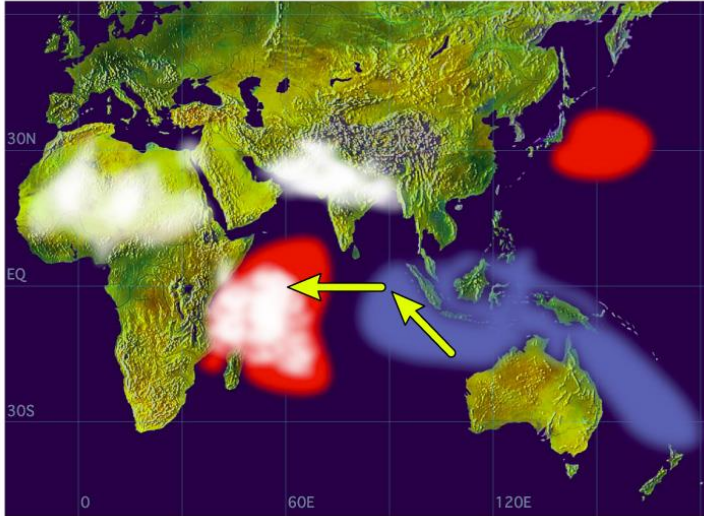
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Indian Ocean Dipole mode (IOD)



Positive Dipole Mode



Explains ~12% of the total variance of tropical Indian Ocean SSTs (Saji et al. 1999, Nature)

Normal conditions

- Surface westerlies
- High SSTs, deep thermocline, and low pressure in the tropical eastern IO (EIO)
- Low SSTs, shallow thermocline, and high pressure in the tropical western IO (WIO)

Positive IOD

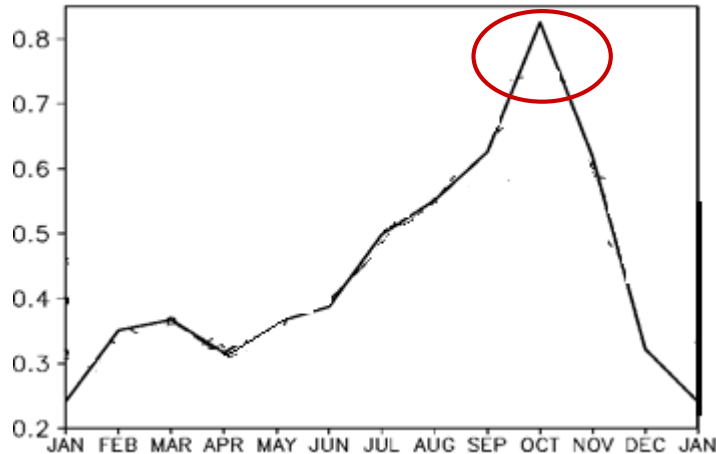
- Break down of surface westerlies
 - Induces anomalous upwelling in the EIO
 - lifts up the thermocline & SSTs become cooler, and pressures become higher in the EIO
 - SSTs become warmer, pressures become lower, and thermocline becomes deeper in the WIO
 - reduce the zonal gradients of SSTs & pressure
 - Induce easterlies → more upwelling in the east
- (+ve Bjerknes feedback)



Indian Ocean Dipole mode



(a) DMI std



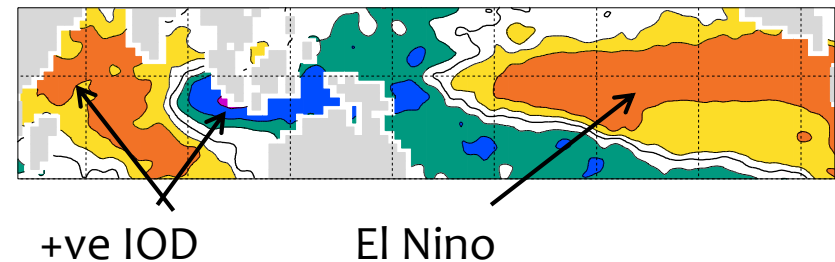
(taken from Zhao & Hendon (2009), their Fig.2)

IOD has a strong seasonality – develop from NH summer, peak in NH fall, and decay in late fall when Australian monsoonal westerlies become strong (e.g. Hendon et al. 2012)

IOD has a strong relationship with eastern Pacific type ENSO in NH fall

→ predictability of the peak season
IOD stems from its relationship with ENSO

Correlation of SST anomalies onto IOD index (DMI) in Sep-Oct-Nov season

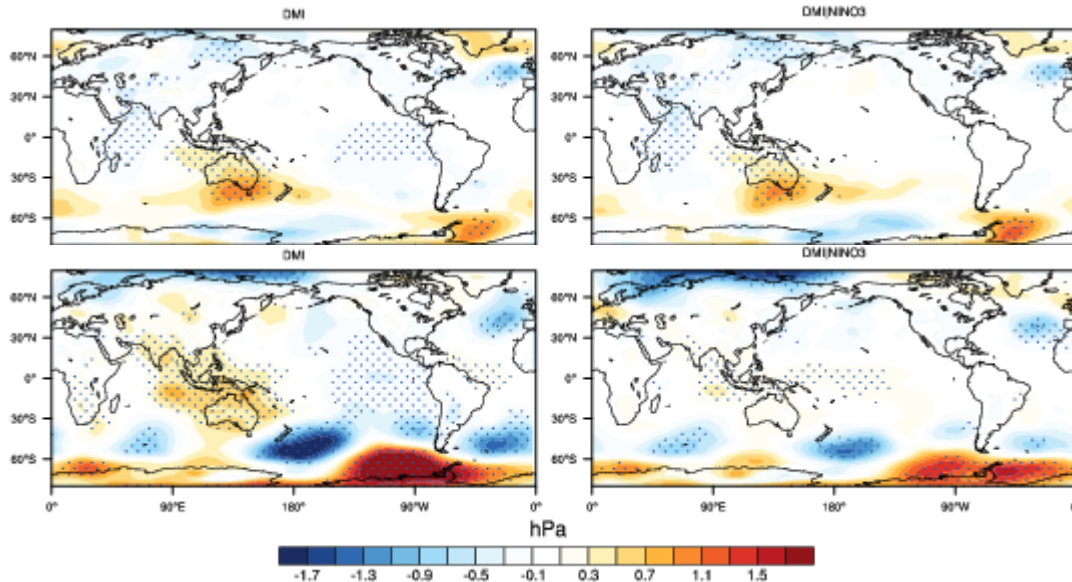


Indian Ocean Dipole



MSLP & IOD

MSLP & IOD without ENSO



JJA

* Statistically significant relationship at 90% c.l. is stippled

SON

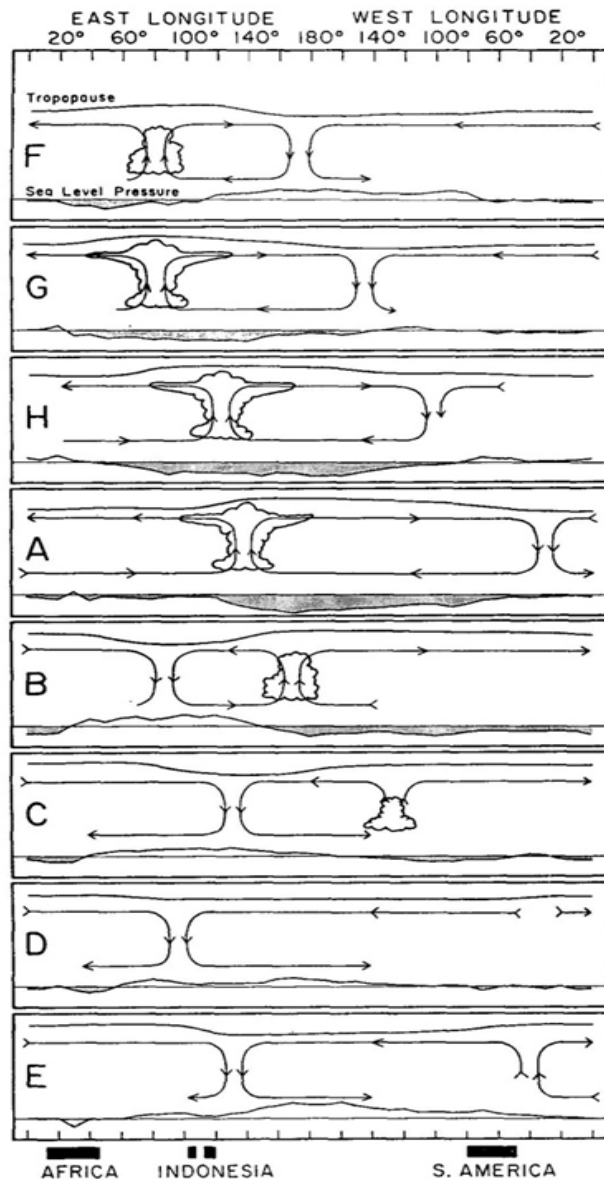
- JJA – IOD impact on the climate of Indian Ocean rim countries and on the climate of central Asian region and eastern Siberia via Rossby wave propagations from the Indian Ocean, independent of ENSO
- SON – IOD impact is stronger and broader, but many of those features are there because IOD often occurs together with ENSO



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Madden-Julian Oscillation



Abstract of a review paper written by Prof. Chidong Zhang in Reviews of Geophysics, vol.43, 1-36

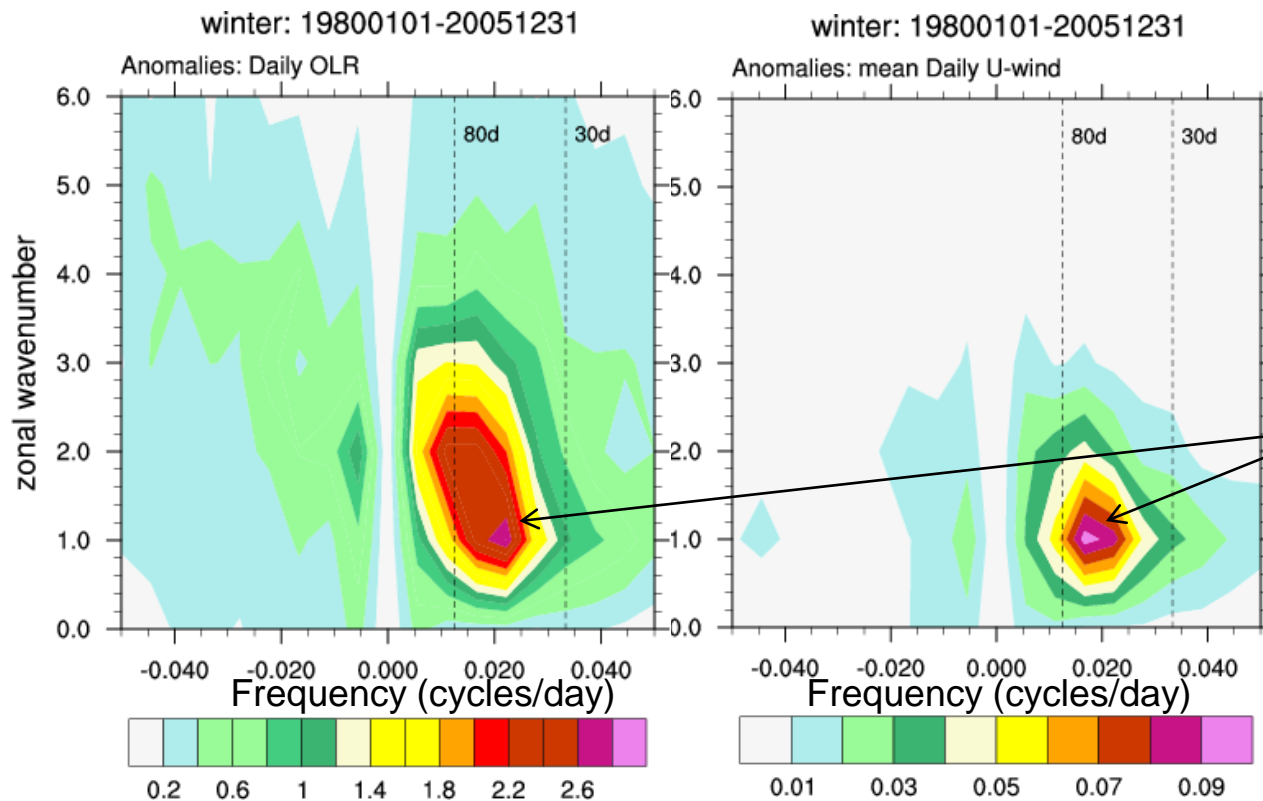
" **The Madden-Julian Oscillation (MJO)** is the dominant component of the **intraseasonal (30–90 days) variability in the tropical atmosphere**. It consists of **large-scale coupled patterns in atmospheric circulation and deep convection**, with coherent signals in many other variables, all **propagating eastward slowly (~5 m/s)** through the portion of the Indian and Pacific oceans where the sea surface is warm. It constantly **interacts with the underlying ocean and influences many weather and climate systems.**"

← taken from Madden & Julian (1972)
each phase spans 4-8 days

MJO



Dominant component of the intraseasonal (~30–90 days) variability in the tropical atmosphere



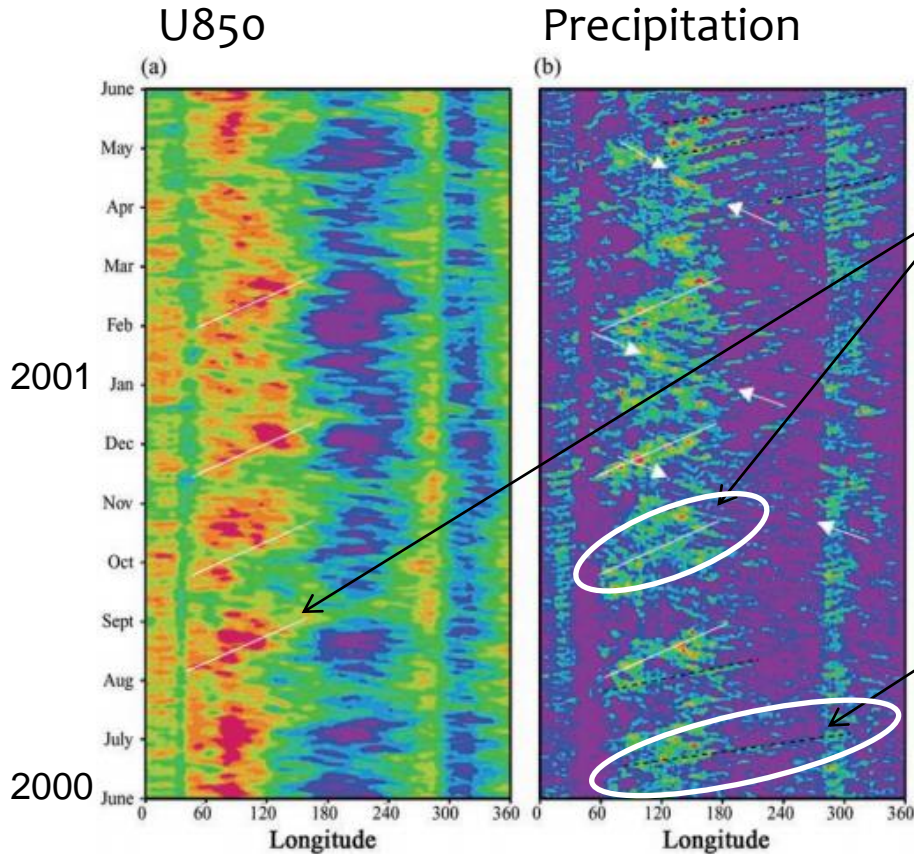
Spectral analysis on daily anomalies of OLR (left) and U850 (right) averaged over the tropics (10S-10N)

peak at 30-100 days & at zonal wavenumber 1-2 (i.e. planetary scale)

from MJO Diagnostics page at

<https://www.ncl.ucar.edu/Applications/mjoclivar.shtml>

MJO



MJO signal in zonal winds and convection propagates eastward at ~5 m/s speed (distinctive from convectively coupled Kelvin waves travelling eastward at 10-15 m/s)

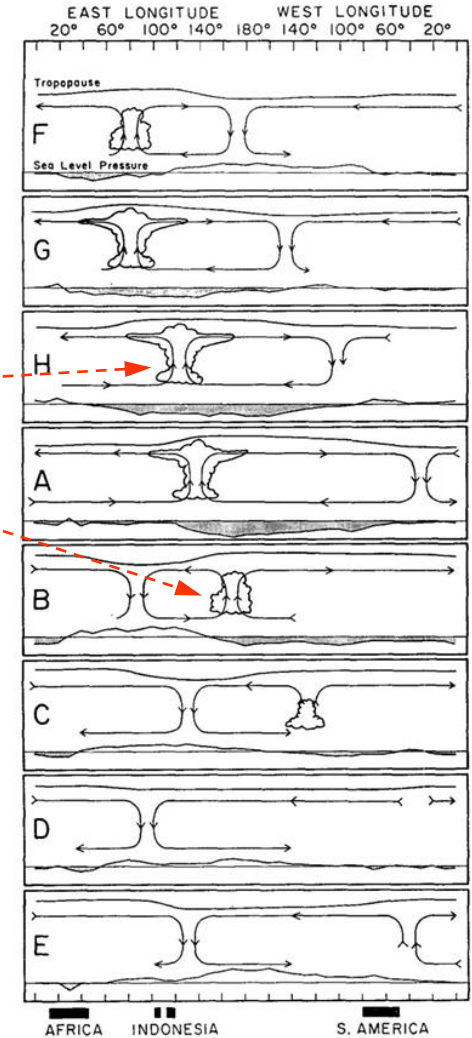
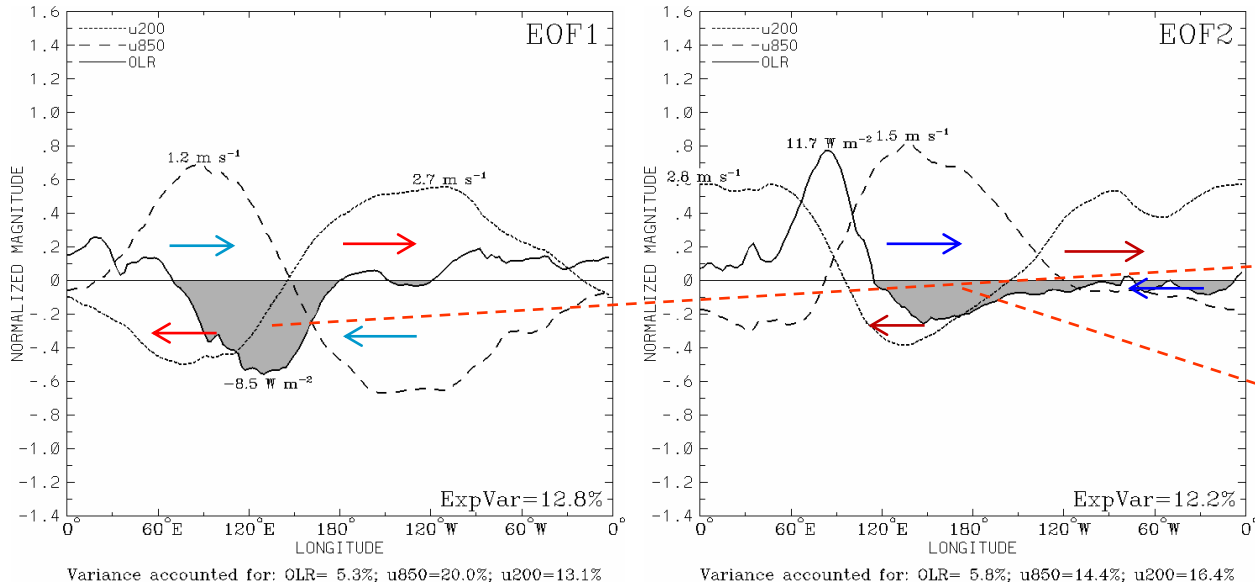
Figure 2. Longitude-time plots of daily (a) zonal wind ($2.5^\circ \times 2.5^\circ$, m s^{-1}) at 850 hPa (roughly 1.5 km above sea level) from the National Centers for Environmental Prediction/National Center for Atmospheric Research (NCEP/NCAR) reanalysis [Kalnay *et al.*, 1996] and (b) precipitation ($1^\circ \times 1^\circ$, mm d^{-1}) from the GPCP combined data set [Huffman *et al.*, 1997] for June 2000 to May 2001, both averaged over 10°N – 10°S . The white straight lines mark identified MJO events, with a slope corresponding to an eastward propagation speed of 5 m s^{-1} . Notice that each MJO event may propagate eastward at a slightly different speed. The faster eastward moving (15 m s^{-1}) signals with shorter periods (5–10 days) (examples marked with black dashed lines) are of convectively coupled Kelvin waves and should not be mistaken for the MJO [e.g., Takayabu *et al.*, 1999]. The westward moving synoptic signals (examples marked with white arrows) are likely of Rossby or mixed Rossby-gravity waves.

← taken from Zhang (2005)



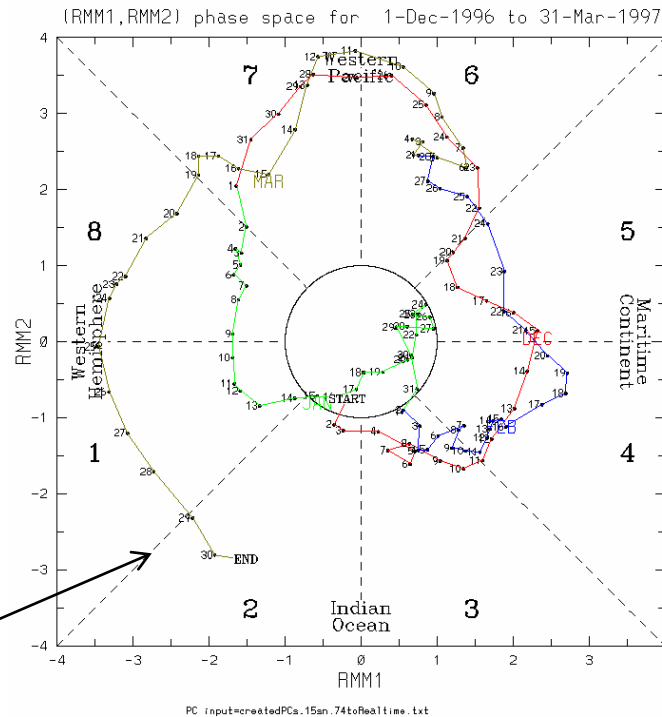
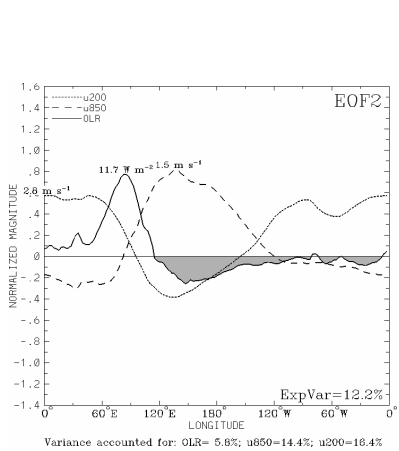
atmospheric circulation and deep convection coupled variability

The Real-time Multivariate MJO (RMM) index

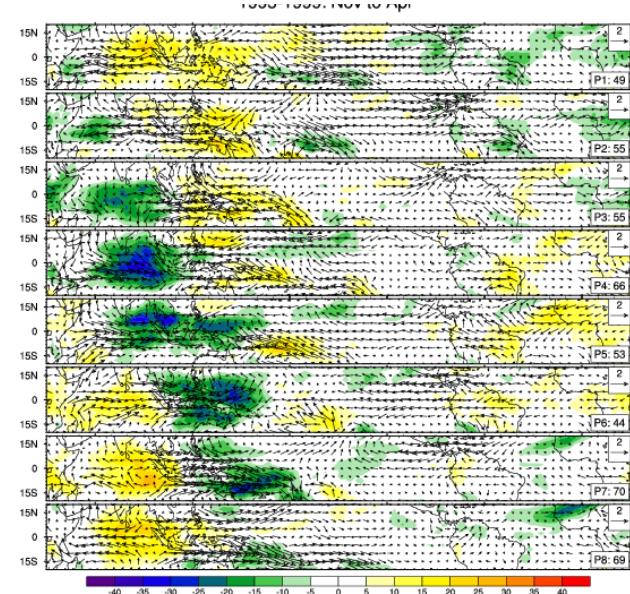


- EOFs of the combined daily anomaly fields of 15S-15N averaged OLR, U850 and U200
- The EOF pair describes the convectively-coupled baroclinic structure of the MJO along the equator & its life cycle
- They are approximately in quadrature (90° cycle shifted)

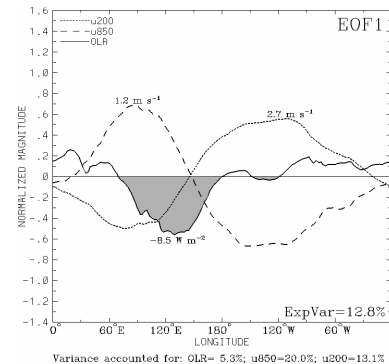
MJO



Composites of OLR and U&V850 anomalies for each phase



- Effectively displaying strength and propagation of MJO
- Widely used for MJO monitoring & forecasting



Daily RMM1, RMM2, MJO phase values are available at <http://www.bom.gov.au/climate/mjo/>

from MJO Diagnostics page at <https://www.ncl.ucar.edu/Applications/mjoclivar.shtml>

Impact of MJO

on precipitation & surface temperature

- Direct impact on
Asian summer monsoon
Australian summer monsoon
American/North American
monsoon

- Remote impact on
Extreme rainfall/snowfall/temperature

Western Africa

Middle East

Asia

Equatorial Africa

Brazil/Chile

North America

VIA modulating Hadley circulation

exciting equivalent barotropic Rossby waves

interacting with other climate modes (e.g.
ENSO, IOD, Arctic Oscillation, North Atlantic
Oscillation)

For more details, see Zhang (2013)



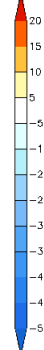
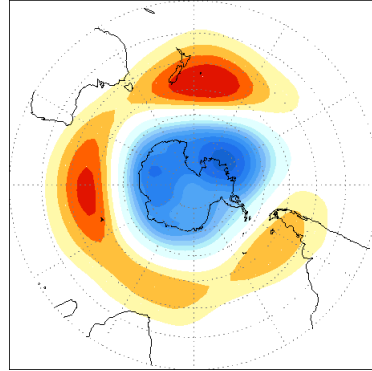
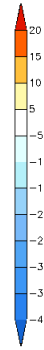
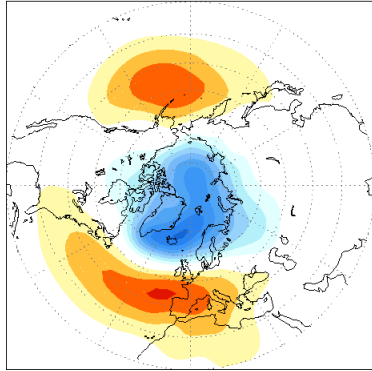
Arctic Oscillation/Antarctic Oscillation

Northern Annular Mode/Southern Annular Mode



Leading EOF (19%) shown as regression map of 1000mb height (m)

Leading EOF (27%) shown as regression map of 700mb height (m)

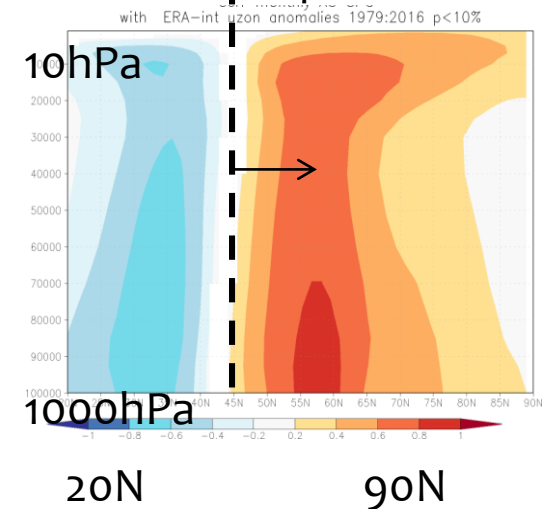


← Taken from

http://www.cpc.ncep.noaa.gov/products/pr/ecip/CWlink/daily_ao_index/ao.shtml

+ve AO

Clim. Jet position

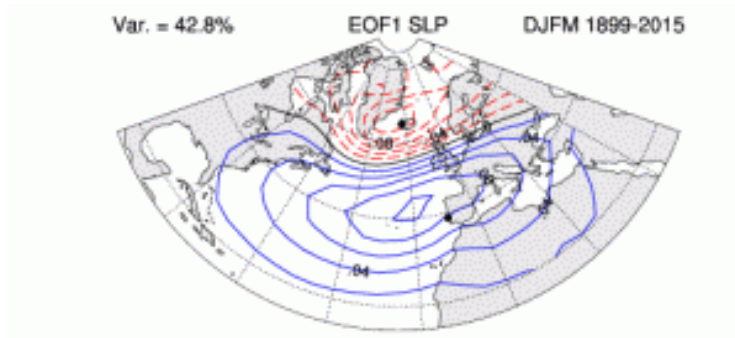


20N

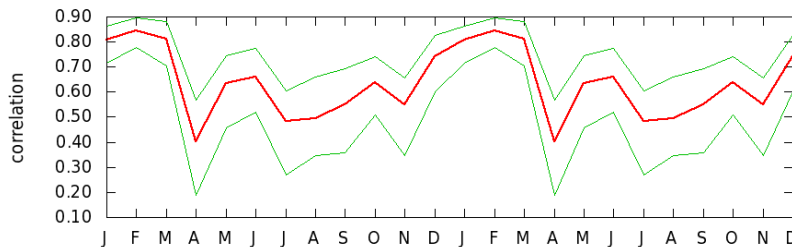
90N

- AO (NAM) and AAO (SAM) are the most dominant modes of variability of the NH and SH extratropical circulations, respectively, in various time scales – from weeks to centuries
- Positive phase of AO/SAM is defined by a poleward shift of the midlatitude jet and associated poleward shift of the synoptic scale extratropical storms
- Reflected in the pressure/geopotential height (GPH) field with zonally symmetric lower pressure (GPH) anomalies in the high latitudes and higher pressure (GPH) anomalies in the midlatitudes
- Weather activity in Europe & North America (Australia, South Africa and South America) is significantly affected by AO (SAM)

North Atlantic Oscillation



Correlation between monthly
NAO & AO



← Taken from

<https://climatedataguide.ucar.edu/climate-data/hurrell-north-atlantic-oscillation-nao-index-station-based>

- The most dominant mode of winter climate variability in the North Atlantic region
- +ve NAO is characterised by higher pressure (GPH) anomalies in the NH subtropics and lower pressure (GPH) anomalies in the NH high latitudes
- NAO is related to AO especially in the winter time (e.g. Deser 2000)
- Weather activity in Europe and North America is significantly influenced by NAO in the NH winter in sub-seasonal time scale

Predictability of AO/NAO/SAM



Basically internally driven atmospheric processes whose decorrelation time is ~ 2 weeks

However, their sub-seasonal time scale variability can be forced by

- ENSO (e.g. Karoly 1989, Fraedrich & Muller 1992, Ineson & Scaife 2008, L'Heureux & Thompson 2006)
- Sudden stratospheric warming (e.g. Baldwin and Dunkerton 1999, Thompson et al. 2005)
- MJO (e.g. Cassou 2008)

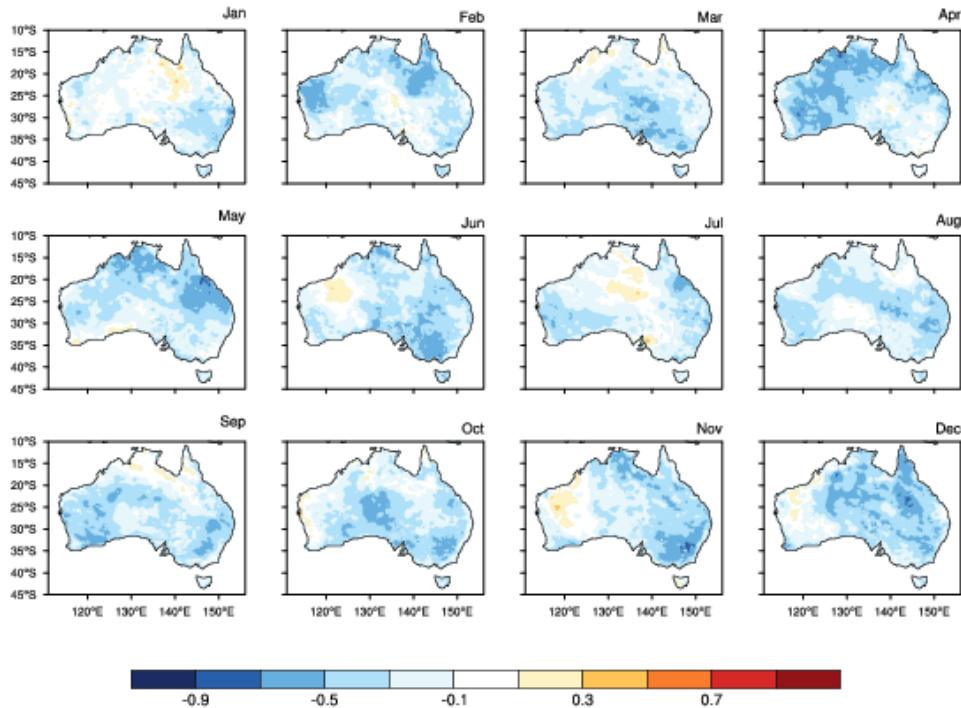
→ AO/NAO/SAM can persist for a longer period (e.g. a few months) and be more predictable when ENSO, SSW or MJO is strong



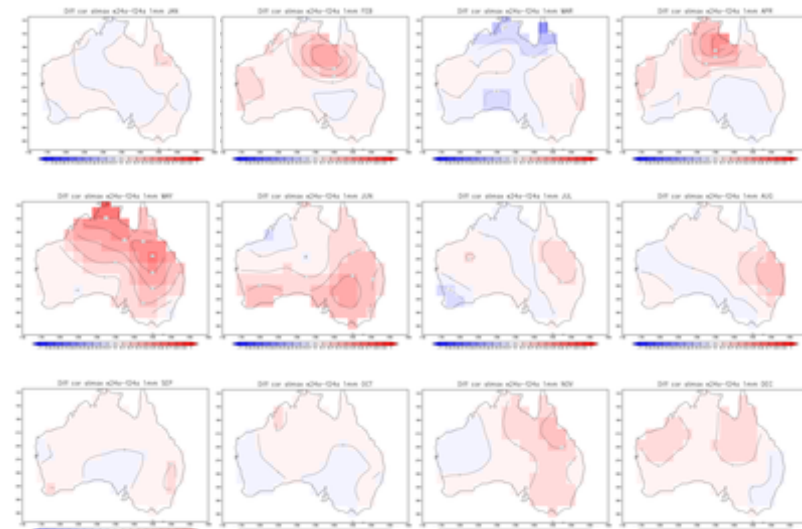
Land



Lag correlation btw upper layer (~0.2m) soil wetness and Australian Tmax



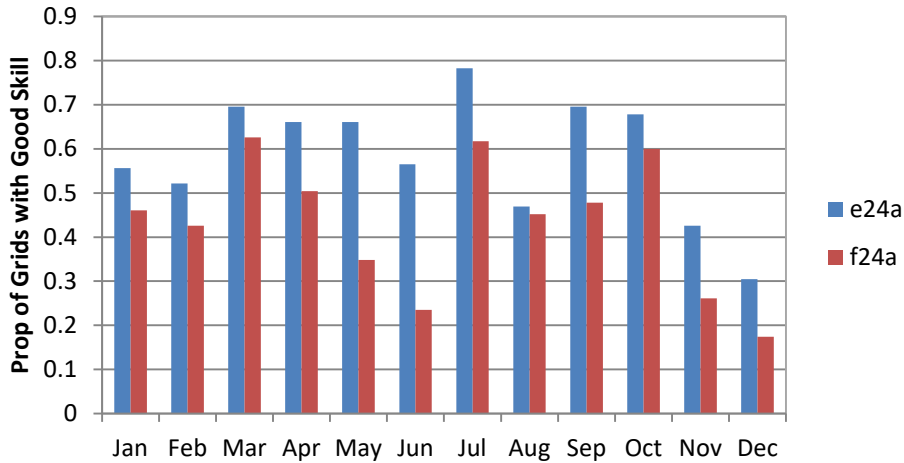
Sensitivity of FCST skill on the initial land surface conditions (realistic vs climatological conditions)



Realistic land initial conditions make → positive contributions to the forecast skill to predict Australian Tmax (red shading)



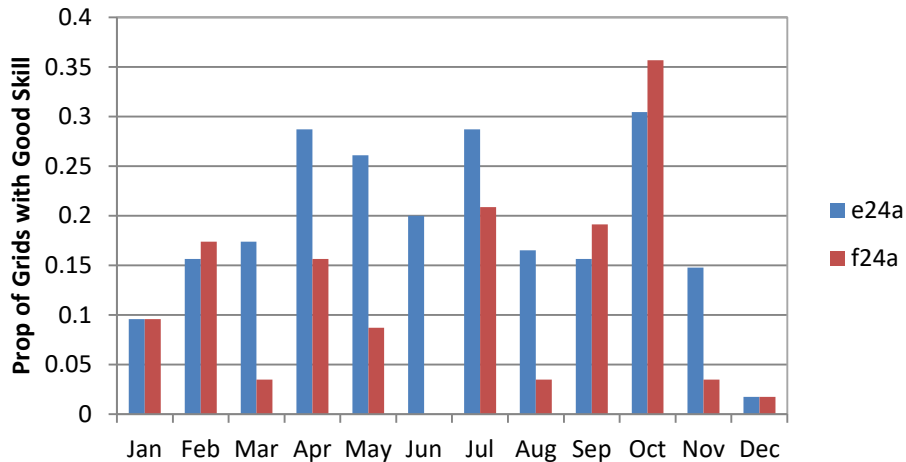
Median Fcst



Proportion of grid points over Australia that demonstrate skillful forecasts for Tmax (above median) and extreme Tmax (top and bottom quintiles)

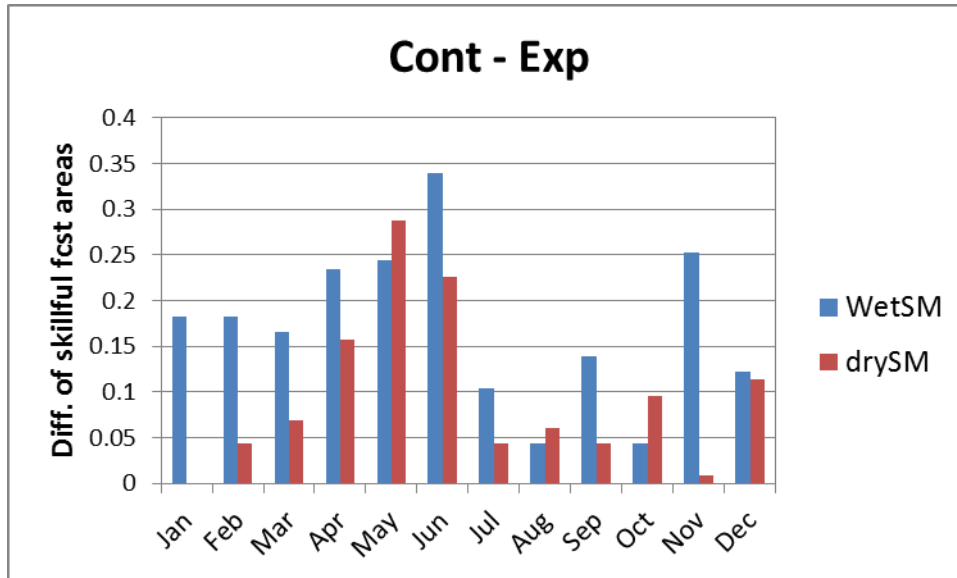
Skillful forecasts: proportion correct is greater than climatological forecasts (for median- $r > 0.55$; quintile $r > 0.25$)

Quintile Fcst



Skill improvement due to realistic soil initial conditions (i.e. blue bars taller than red bars) is found all year round for Tmax and in autumn and winter months (March to August) for extreme Tmax

Realistic soil – climatological soil ICs



- Fcst skill for Australian Tmax is higher when the initial soil is wet and lower Tmax is predicted than when the initial soil is dry and higher Tmax is predicted
→ Skill improvement by realistic land initial conditions is greater for wet soil – low Tmax than dry soil – high Tmax

Summary

- Atmosphere-Ocean coupling in the tropics provides predictability to S2S climate
 - ENSO (different "flavors" of El Nino)
 - IOD
 - local SSTs (atmosphere immediately responds to anomalies in lower boundary (SST/land surface), which persists at least for ~1mth)
- MJO
- AO/NAO/SAM
- Land surface
- Other climate processes? – e.g. sea-ice, snow cover

- These climate processes are important to regional S2S climate & enable regional climate to be predictable in S2S time scales
- Therefore, skilful prediction of these climate processes are important for regional climate prediction



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Useful computing resources for climate research



The NCAR Command Language (Version 6.2.1) [Software]. (2014). Boulder, Colorado: UCAR/NCAR/CISL/VETS. <http://dx.doi.org/10.5065/D6WD3XH5>

Main page:

<http://www.ncl.ucar.edu/index.shtml>

MJO diagnostics

<https://www.ncl.ucar.edu/Applications/mjoclivar.shtml>

KNMI Climate Explorer

<http://climexp.knmi.nl>

