Indo-Pacific warming and its impacts on the MJO and global rainfall patterns

1. **The Indo-Pacific warm pool is rapidly warming**

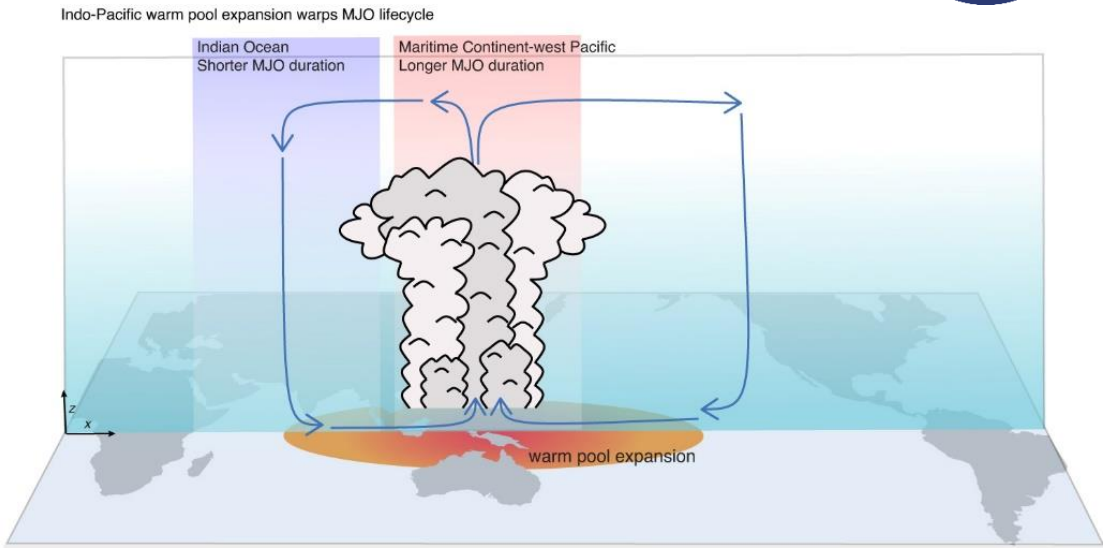
and expanding at the size of California every year (400,000 km^2)

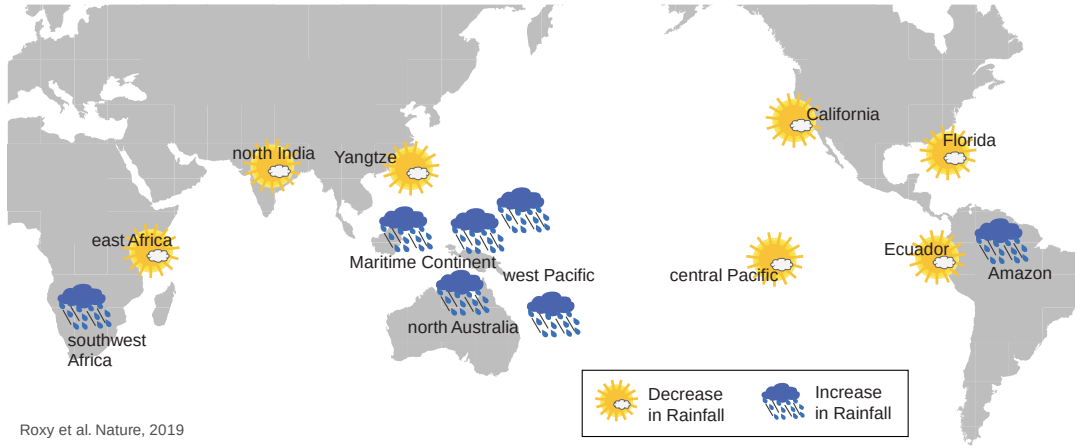
2. **This has changed the residence time of the MJO**
   - — shortened over Indian Ocean (3–4 days)
   - — prolonged over West Pacific (5–6 days)

3. **Thereby altering global rainfall patterns**

increased rainfall over Maritime Continent, north Australia, Southwest Africa, Amazon

drying over US, Central Pacific, Ecuador, East Africa, Yangtze in China and north India





Roxy et al. Nature, 2019

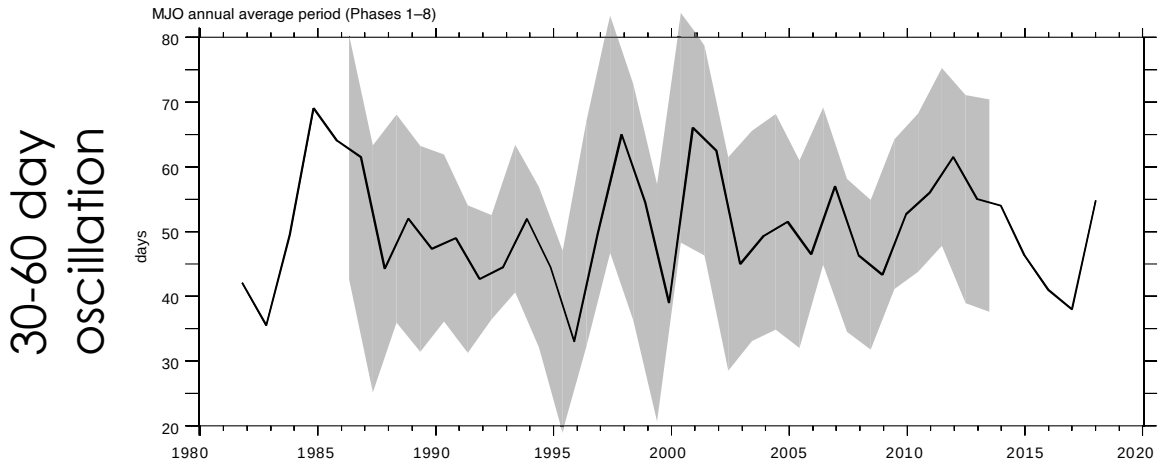
Roxy Mathew Koll[1], Panini Dasgupta[1], Michael J. McPhaden[2], Tamaki Suematsu[3], Chidong Zhang[2] & Daehyun Kim[4]

[1] Indian Institute of Tropical Meteorology | [2] PMEL, NOAA | [3] U. Tokyo | [4] U. Washington

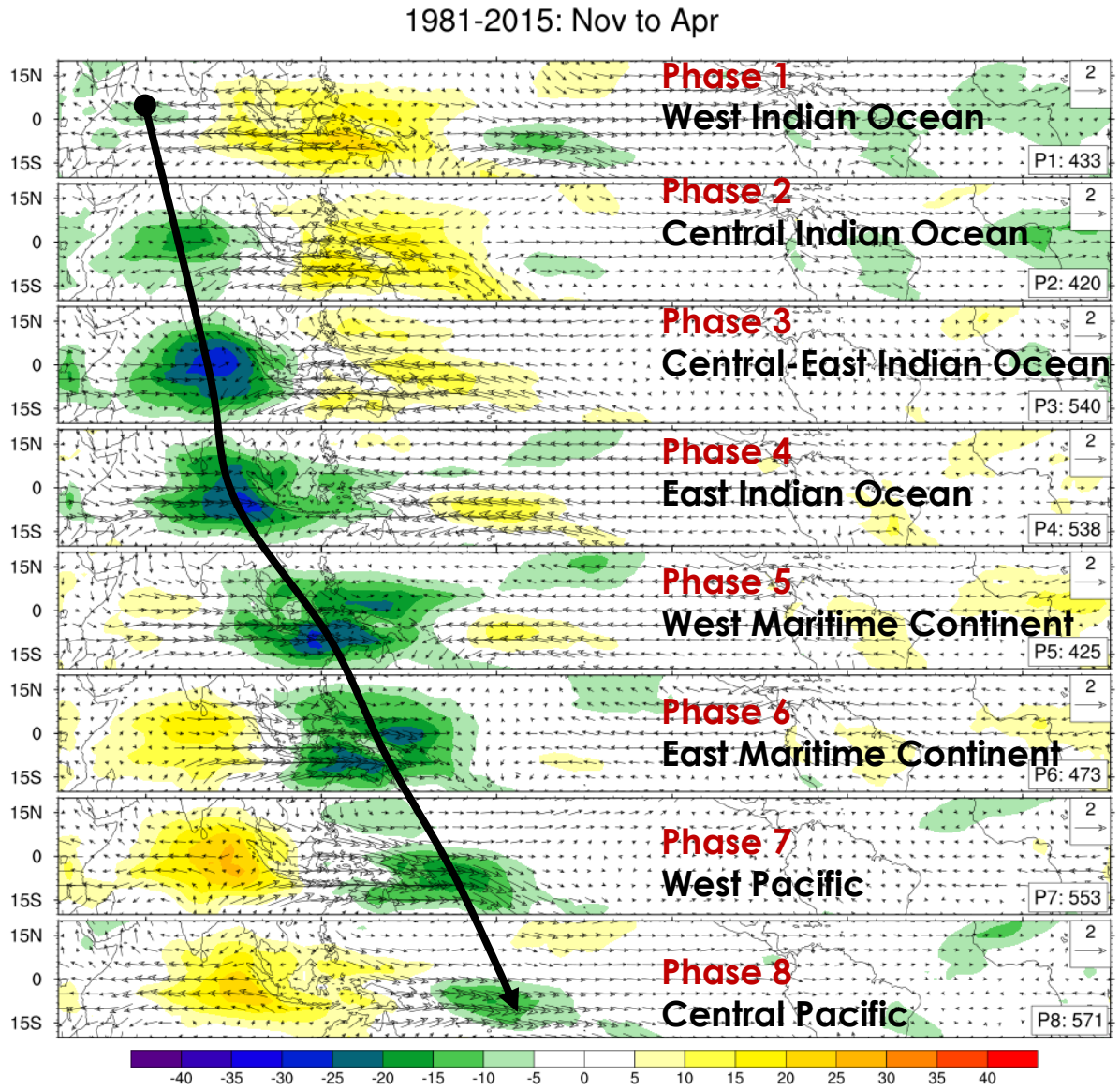
The Madden Julian Oscillation (MJO)

Madden Julian Oscillation (MJO)
— dominant mode of weather variability in the tropics (55%)
— travels over 12,000–20,000 km over tropical oceans

The MJO playground — the tropics — have warmed rapidly, but we do not know how it has impacted its characteristics.



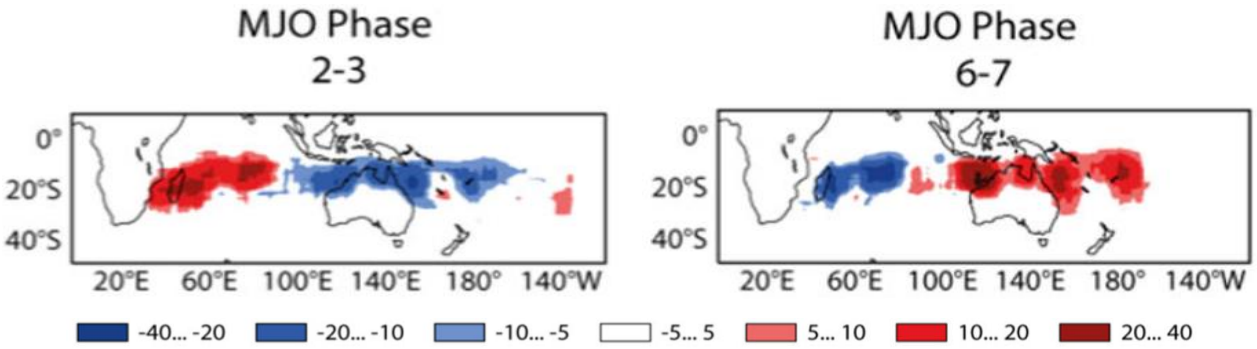
Studies (mostly numerical modeling) have suggested changes in MJO amplitude, frequency and propagation although a clear understanding based on observations is pending.



Jones and Carvalho *QJRMS* 2011; Adames et al. *JAMES* 2017; Maloney et al. *Nature Clim. Change* 2019

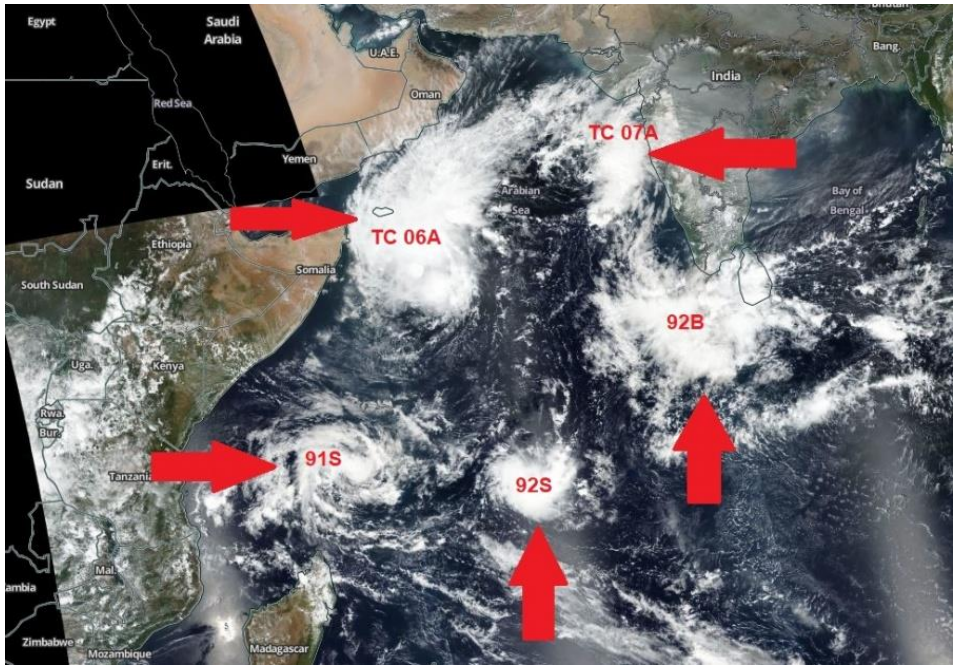
MJO Phases matter

Tropical storm density anomalies (1999–2010)
MJO phase 2–3: tropical storm density is larger over Indian Ocean
MJO phase 6–7: tropical storm density is larger over maritime/west Pacific



Recent feast of storms in the West Indian Ocean that led to locust outbreaks
- Dec 2019

The perfect recipe for multiple storms:
Ocean conditions
— a positive Indian Ocean Dipole over a rapidly warming Arabian Sea
Atmospheric conditions
— MJO in phase 2–3

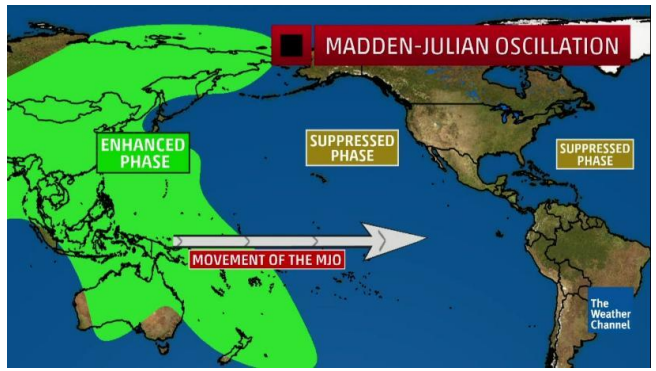


Jiang et al. *JGR* 2017 Klotzbach and Oliver *GRL* 2015

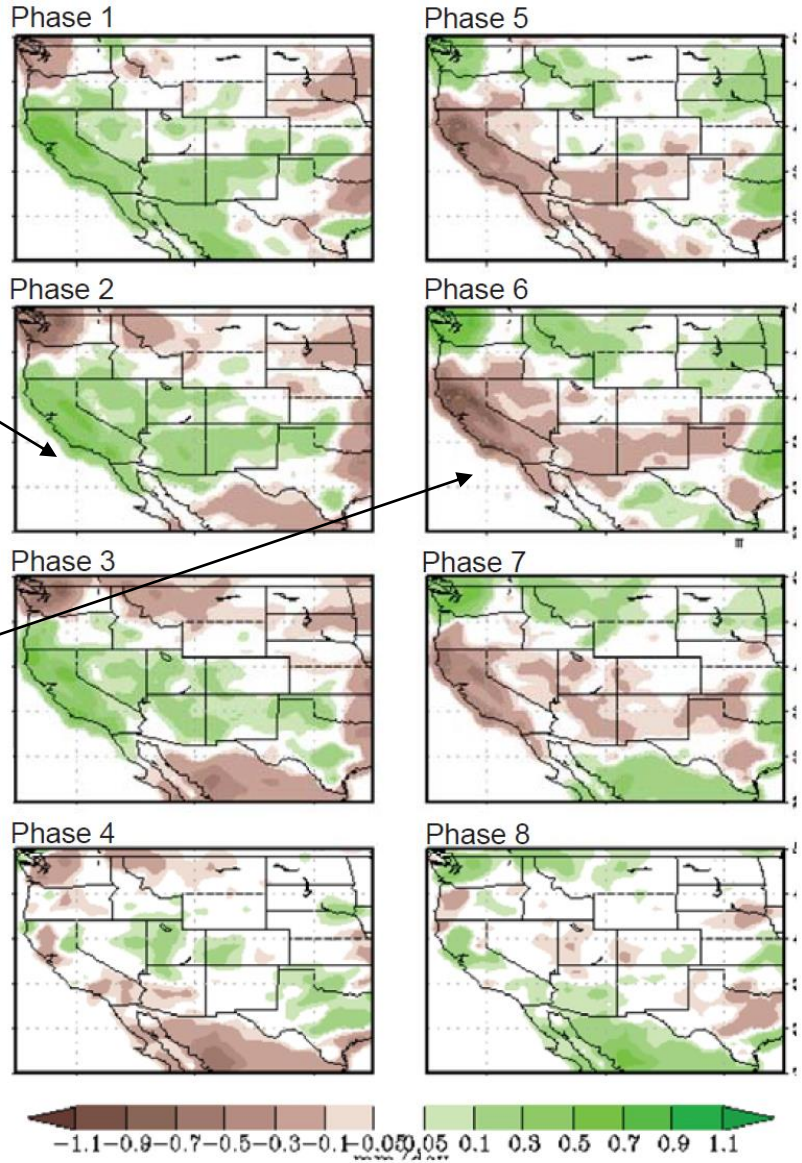
MJO Phases matter

When MJO is over the Indian Ocean (phase 1/2/3), US is wet and cool

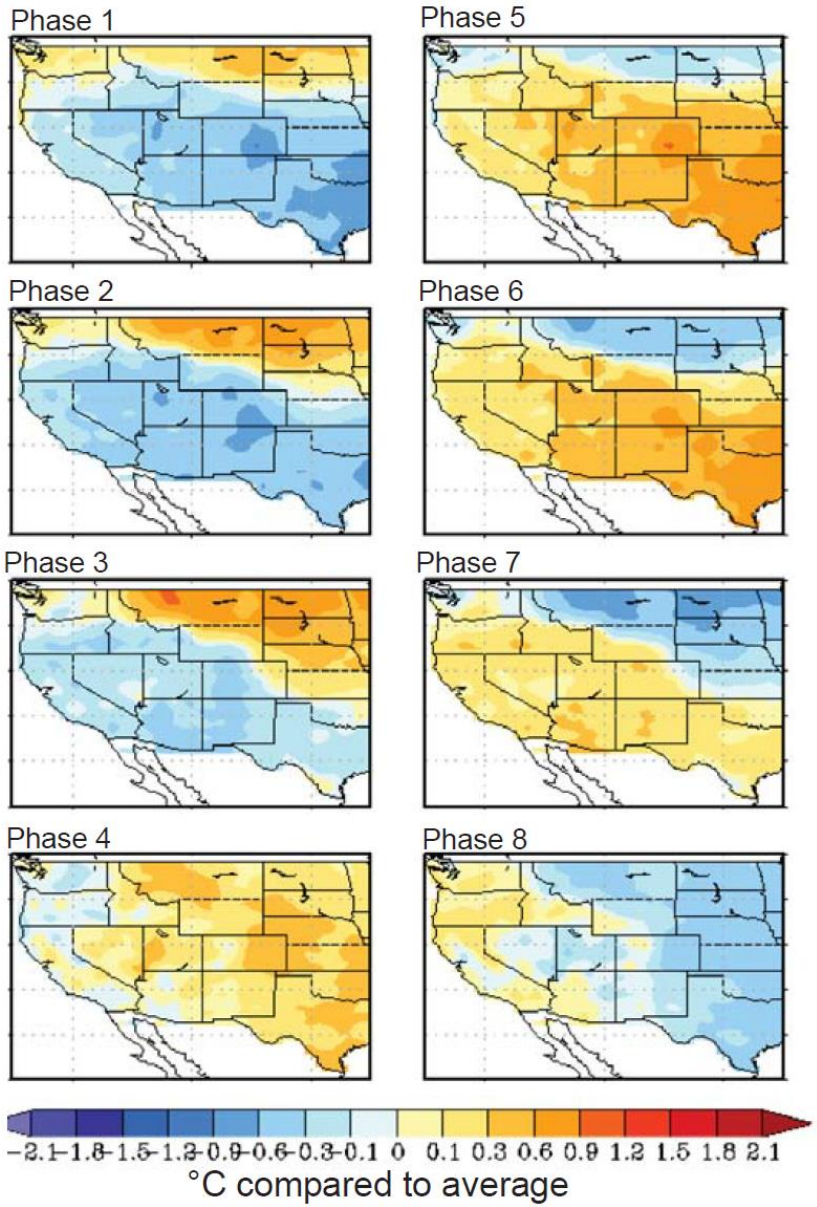
When MJO is over the maritime/W.Pacific (phase 5/6/7), US is dry and warm



Rainfall during MJO phases

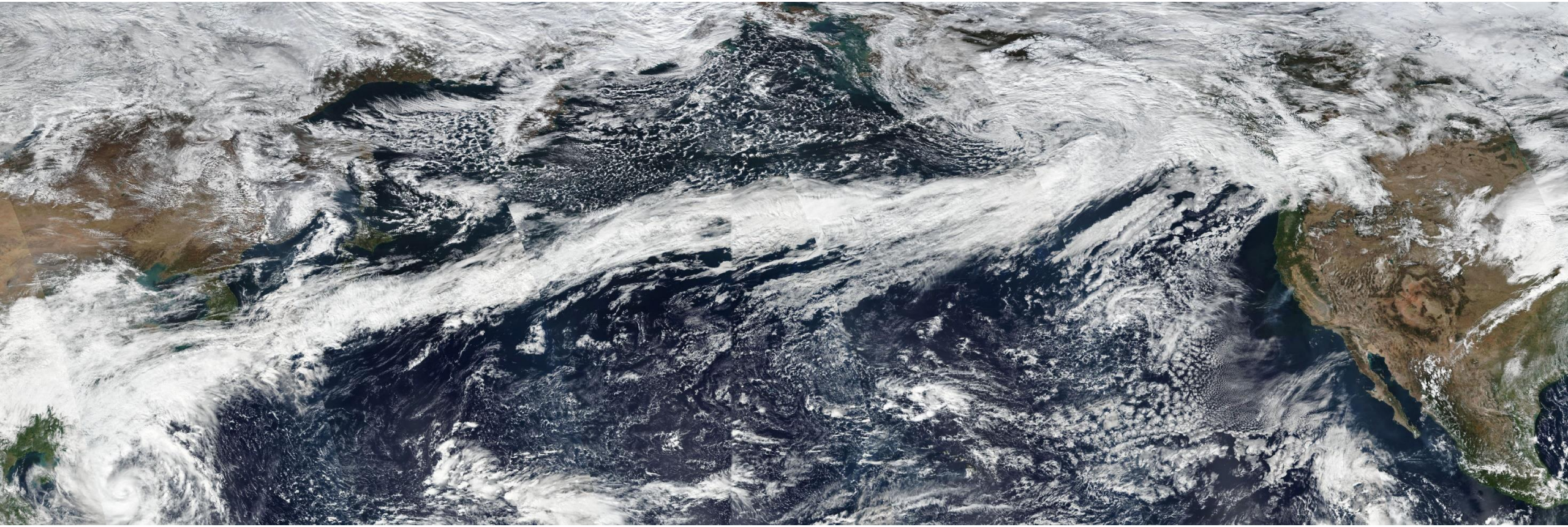


Temperature during MJO phases



Gottschalck 2008 CPC, NCEP/NOAA

The Pineapple Express



Tropical oceans have warmed rapidly in the recent decades

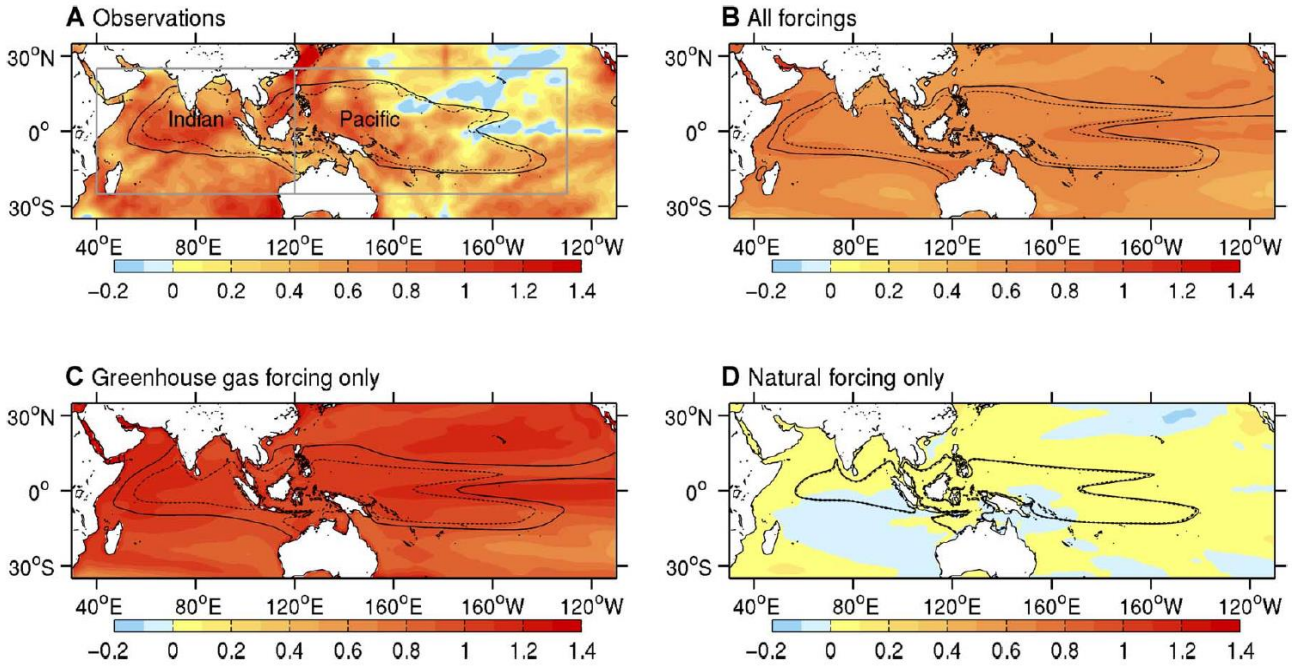
Indo-Pacific warm pool is expanding due to anthropogenic emissions

RESEARCH ARTICLE

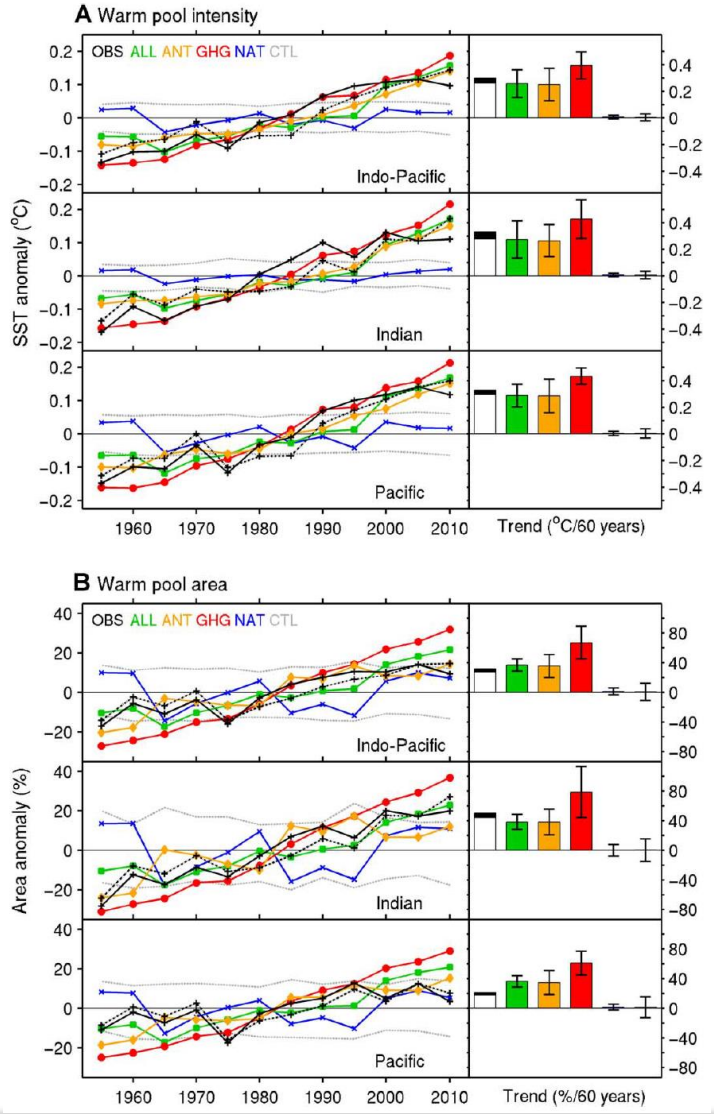
CLIMATOLOGY

Human-caused Indo-Pacific warm pool expansion

Evan Weller,[1] Seung-Ki Min,[1]* Wenju Cai,[2,3] Francis W. Zwiers,[4]
Yeon-Hee Kim,[1] Donghyun Lee[1]



Intensity and area are larger in climate model simulations with greenhouse gas

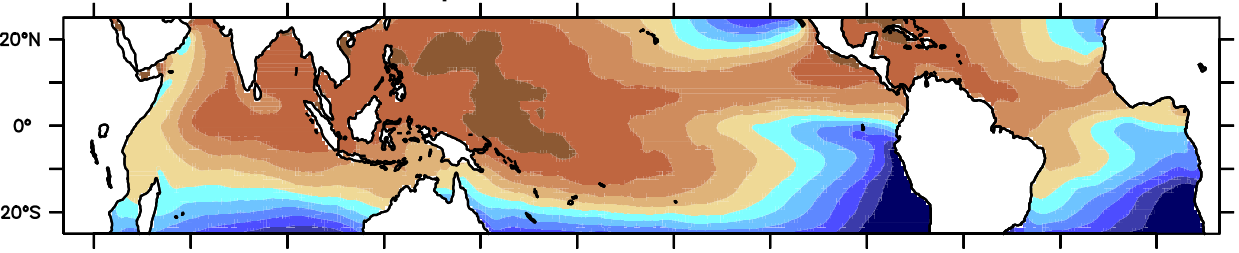


Tropical oceans have warmed rapidly in the recent decades

Indo-Pacific warm pool [Sea Surface Temperatures (SST) above 28°C]
has expanded zonally and meridionally in the recent decades
— this warming is uneven

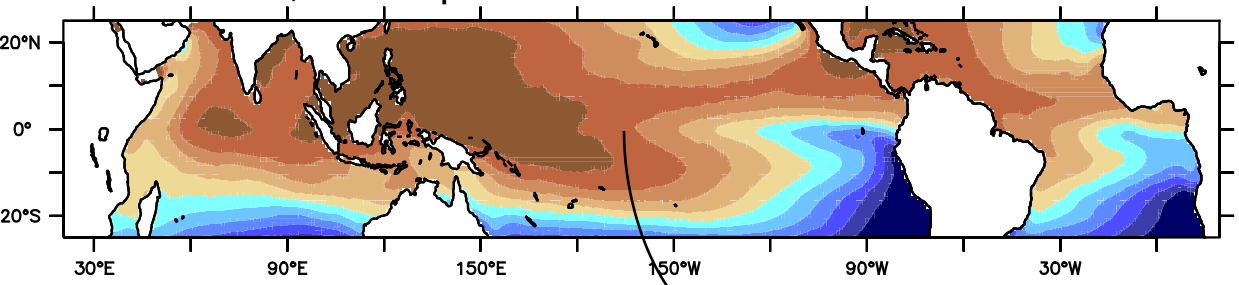
Summer

SST Mean, Jun-Sep 1900-1980



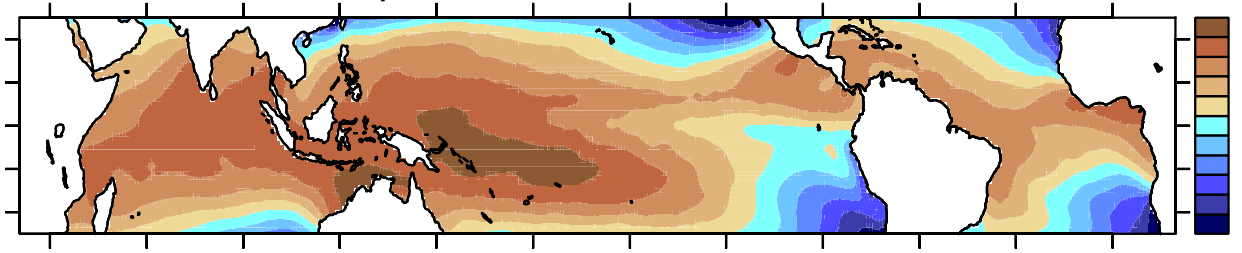
warm pool expansion

SST Mean, Jun-Sep 1981-2018



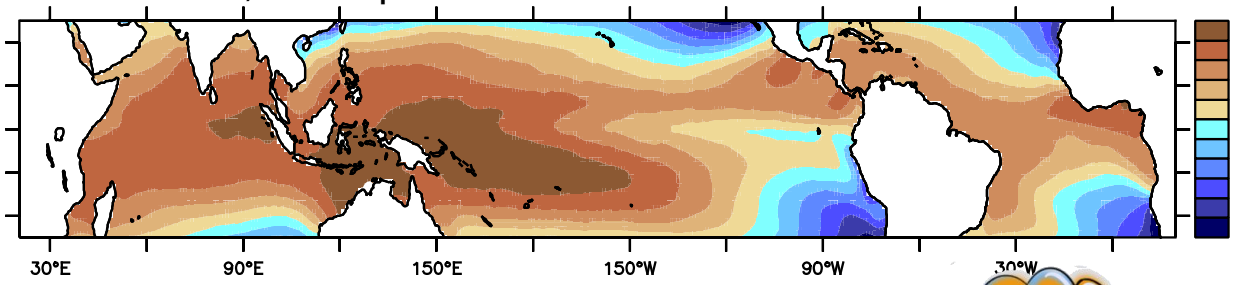
Winter-Spring

SST Mean, Nov-Apr 1900-1980



warm pool expansion

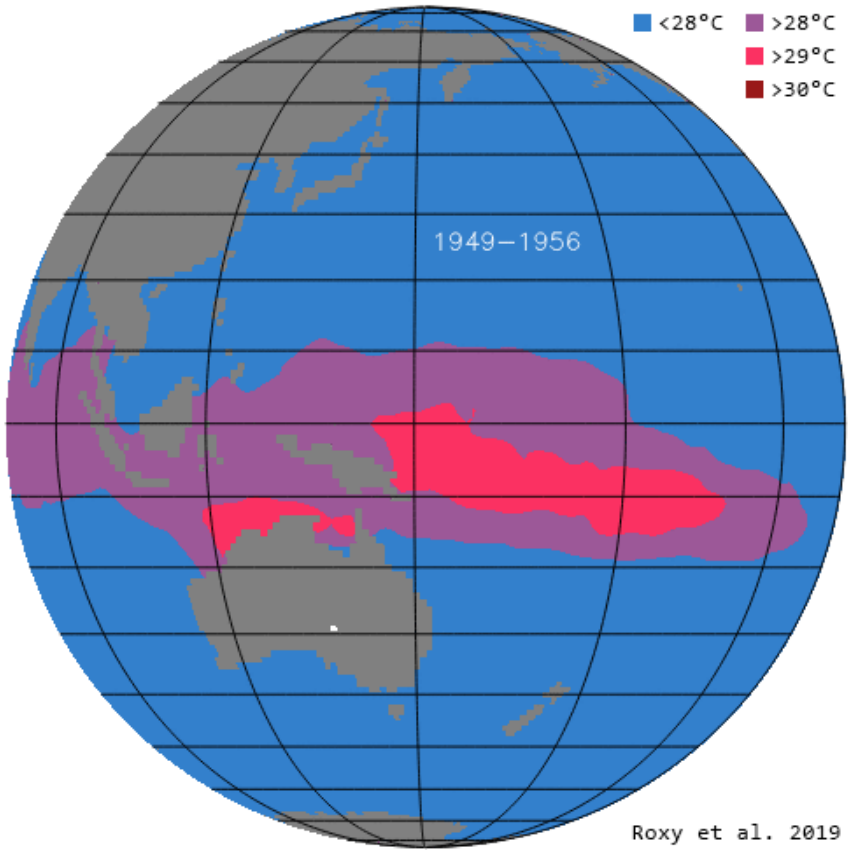
SST Mean, Nov-Apr 1981-2018



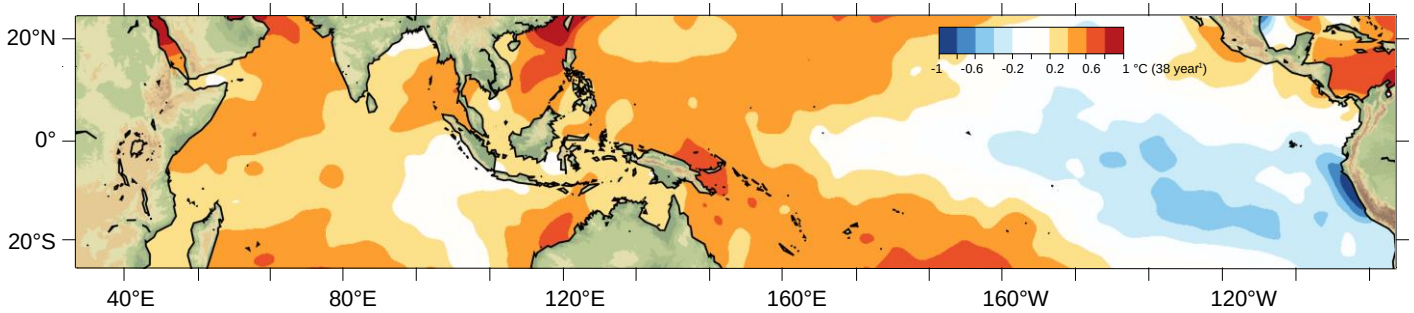
deep brown colors indicate warm pool
—above 28°C

Tropical oceans have warmed rapidly in the recent decades

SST Changes during 1950–2018
7-year averages

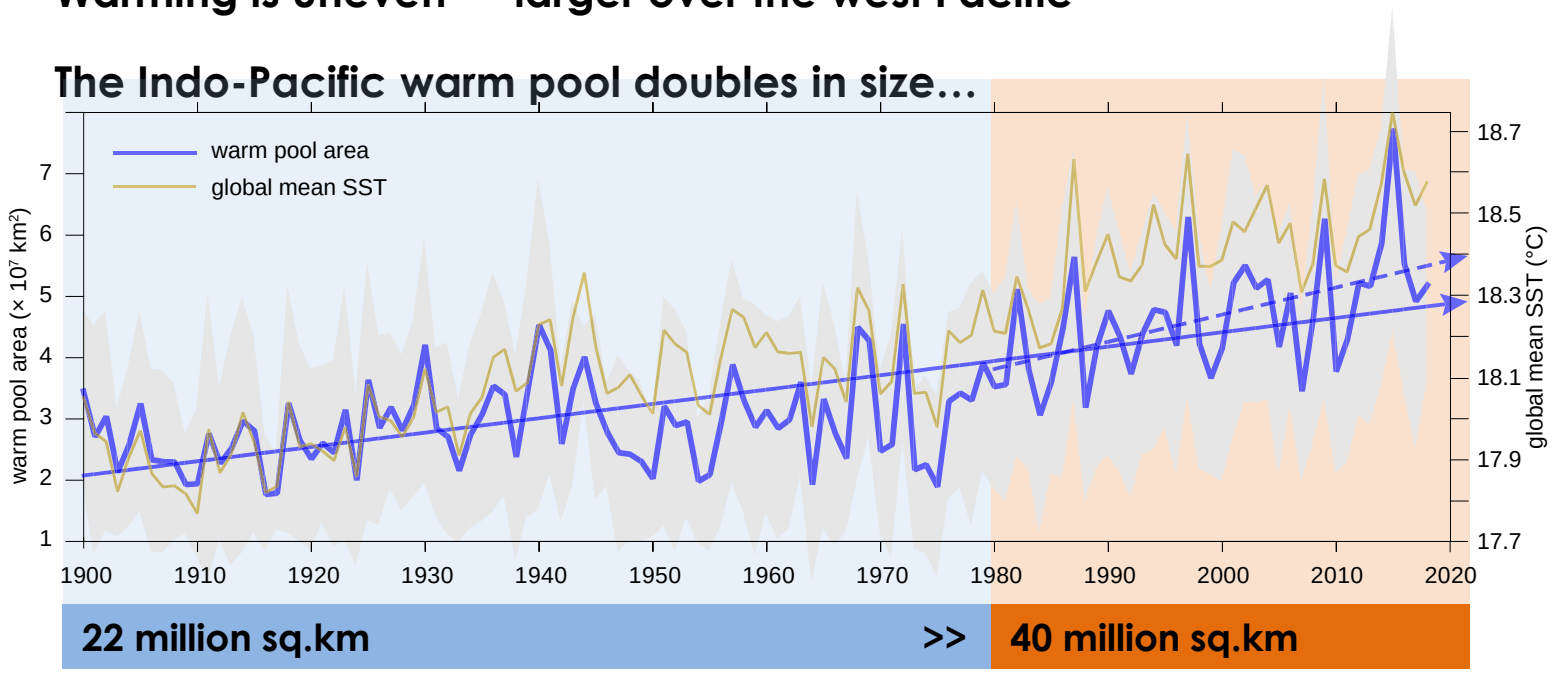


SST trends during the recent decades (1981–2018)



Warming is uneven — larger over the west Pacific

The Indo-Pacific warm pool doubles in size…



22 million sq.km **>>** **40 million sq.km**

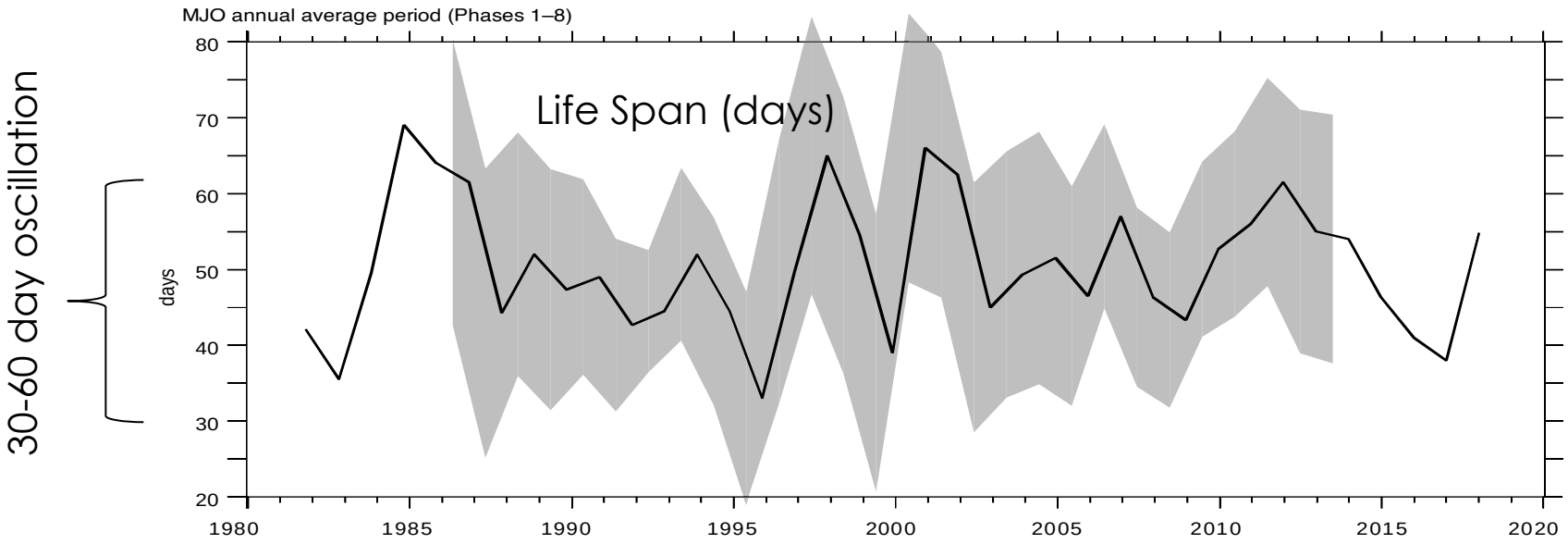
rate of expansion: 230,000 sq.km
State of WA every year

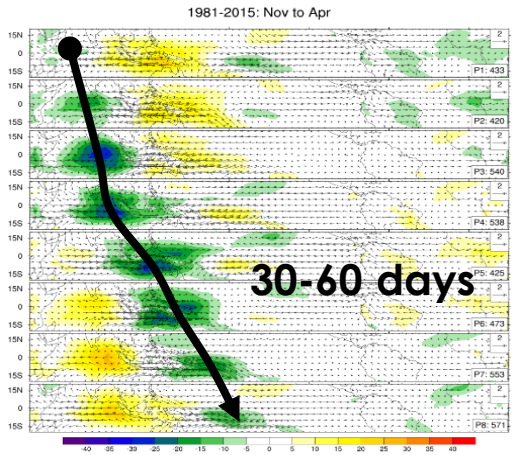
rate: 400,000 sq.km
(CA every year)

A statistical breakpoint analysis confirms that the shift to higher warm pool values occurred in the annual series during 1979–1980.

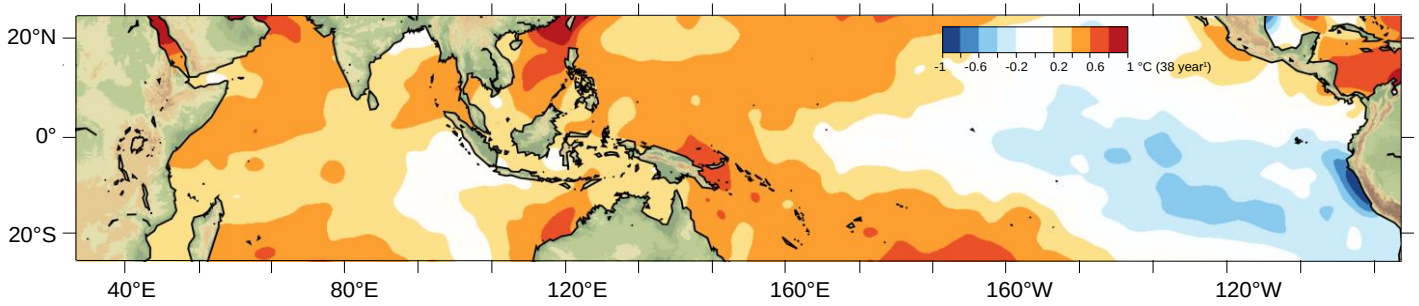
How has the MJO lifespan changed over time?

—no significant change in total lifespan





But we know that the warming is uneven
— does it impact individual phases?

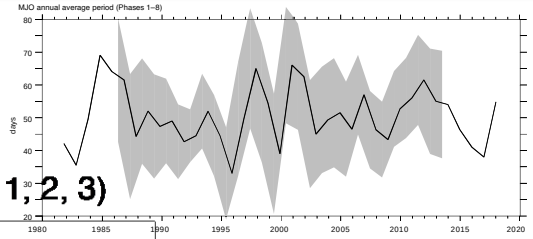


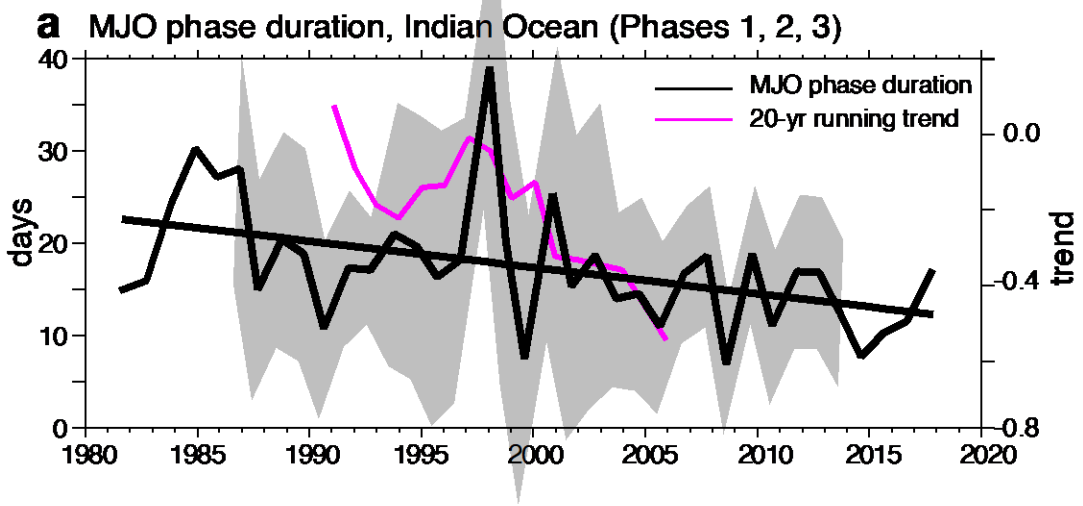
MJO Selection >>
— MJO events during Nov–Apr [1981–2018]
— RMM index is > 1
— strong coupling between tropical convection and largescale circulation
— prominent active eastward propagation (P1/2/3 to P6/7/8)
— Interannual variation + ENSO are removed

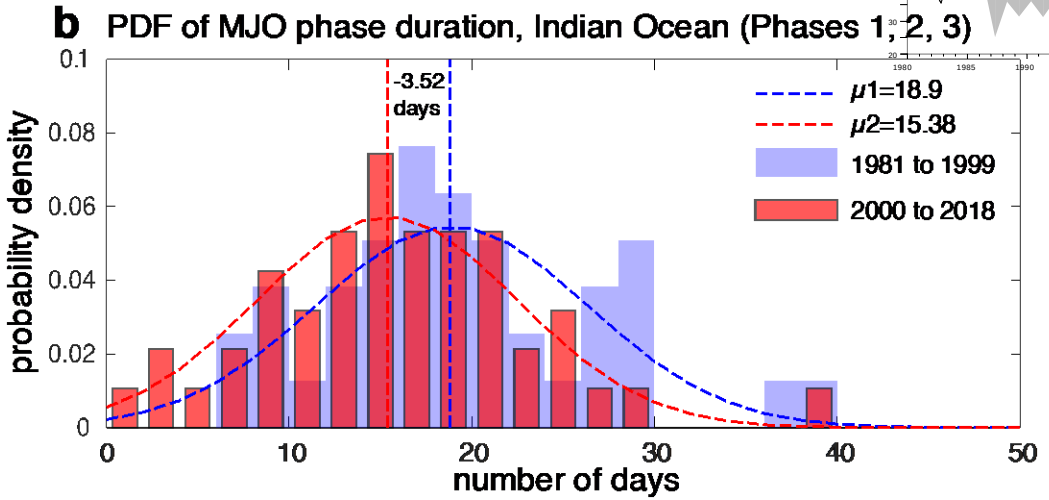
Individual phase duration = MJO at each RMM phase

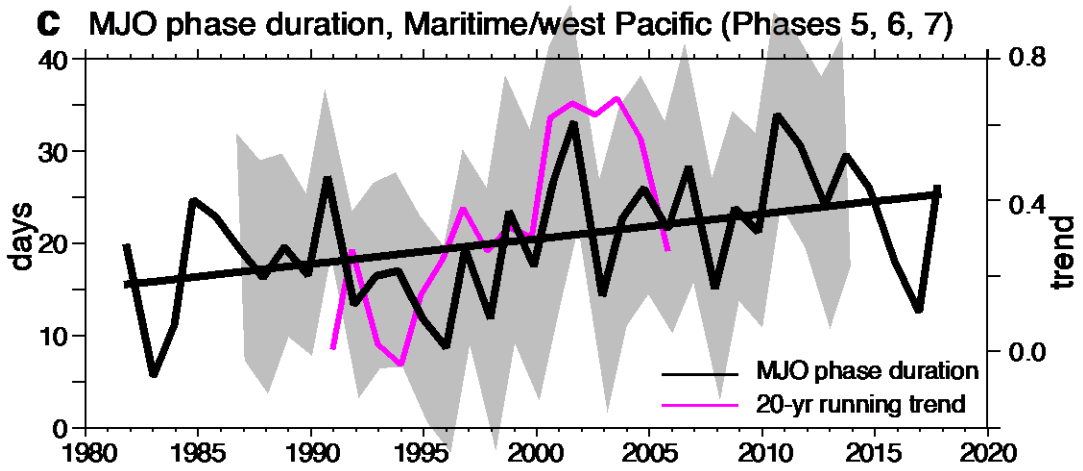
What about the MJO lifespan at different phases?

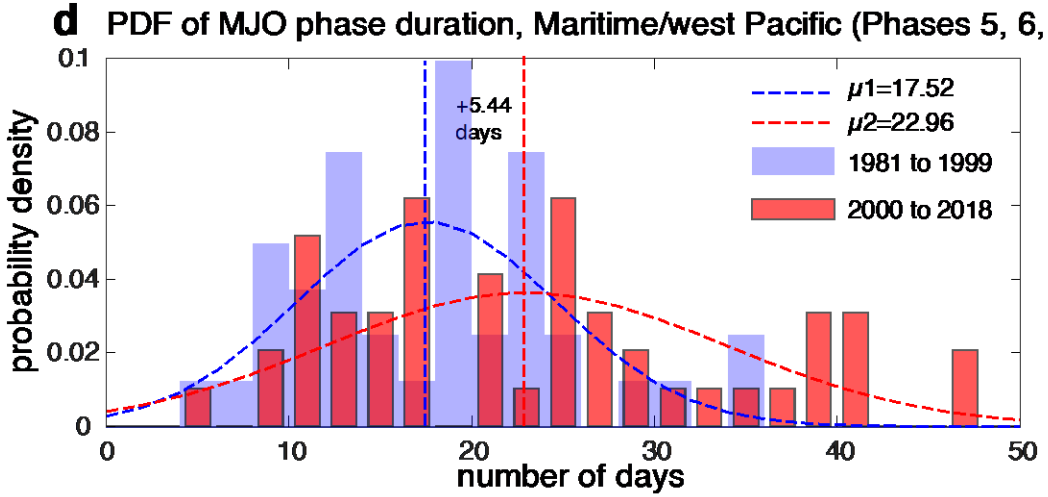
— MJO spends more time at Maritime/West Pacific (5,6,7) and less at Indian Ocean (1,2,3)







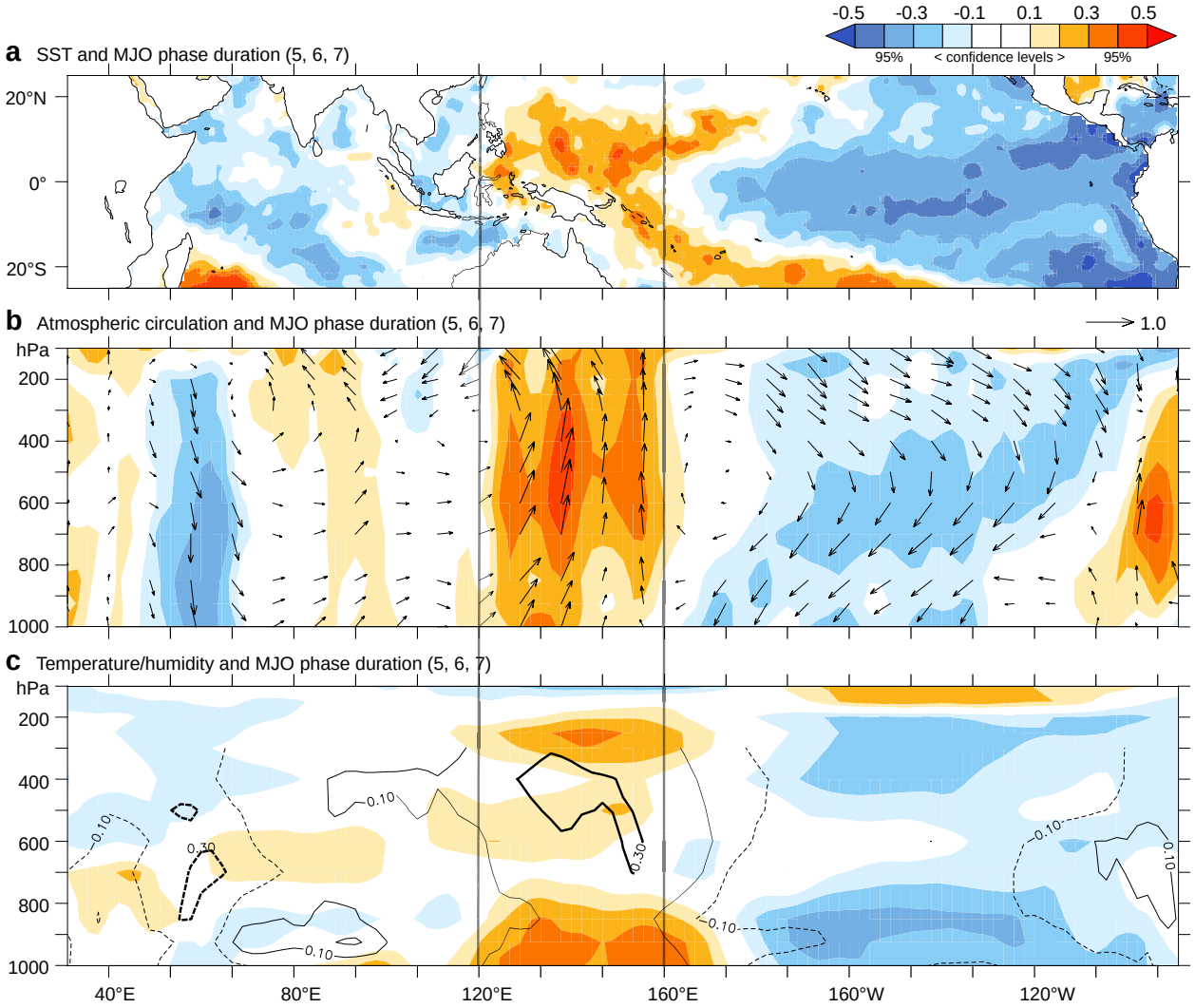




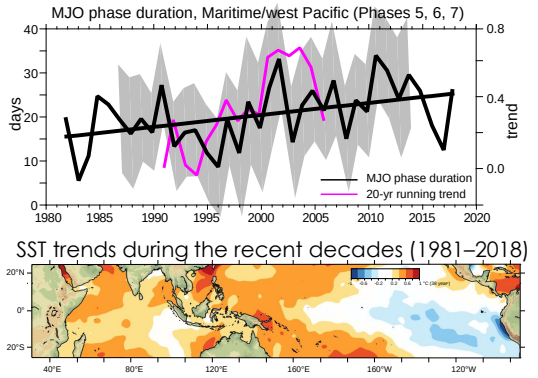
Difference in the duration is statistically significant under a Mann-Whitney U test

Change in MJO life span related to ocean warming

Correlation between MJO phase duration and
(a) SST, (b) atmospheric circulation and (c) temperature/ humidity

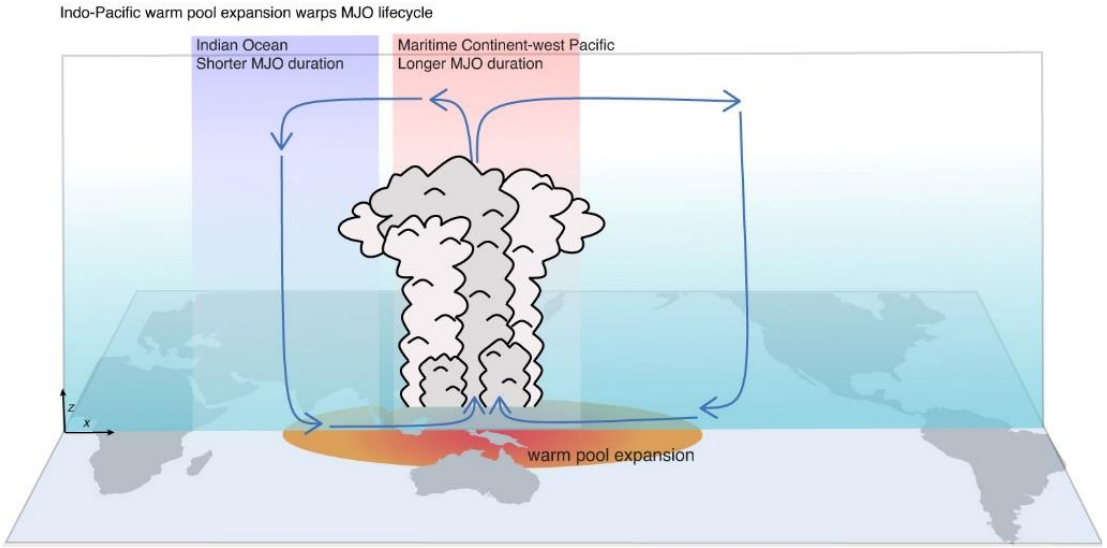


➔ **MJO changes over Maritime/ west Pacific (and also the Indian Ocean) are largely driven by SST warming over west Pacific**



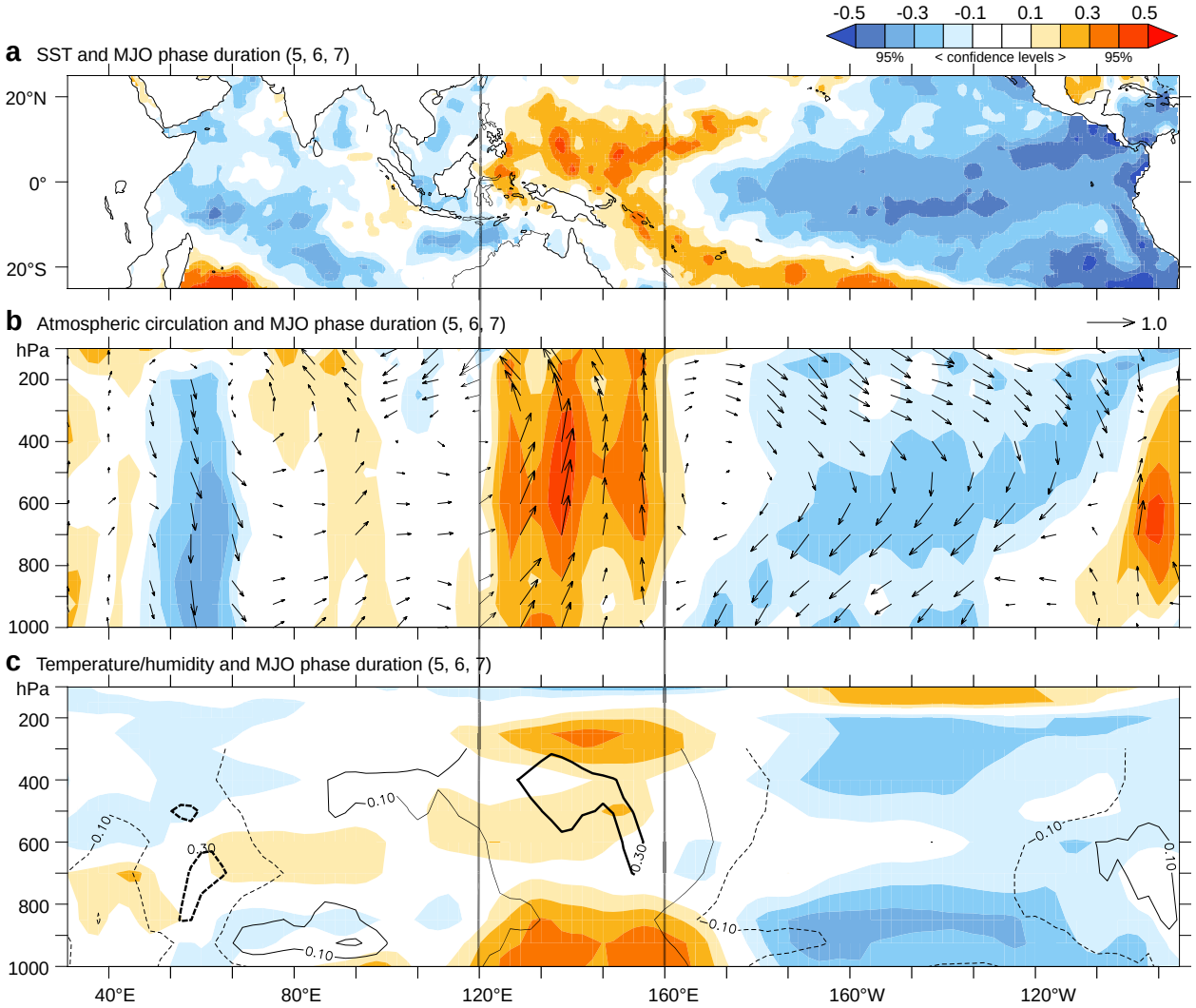
Mechanism

While the warm SST trend in the west Pacific prolongs the local convective activity, it also drives dry air subsidence over the Indian Ocean

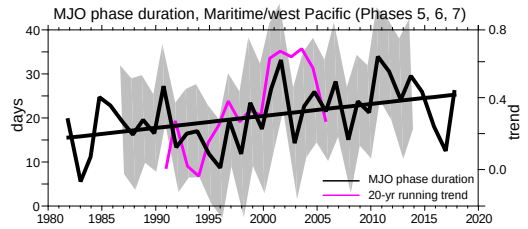


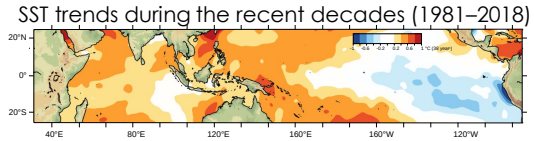
Change in MJO life span related to ocean warming

Correlation between MJO phase duration and
(a) SST, (b) atmospheric circulation and (c) temperature/ humidity



➔ **MJO changes over Maritime/ west Pacific (and also the Indian Ocean) are largely driven by SST warming over west Pacific**

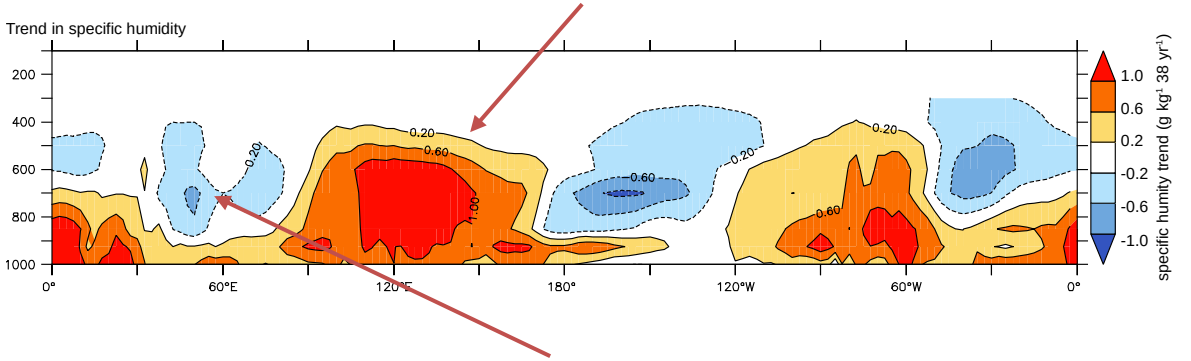




Mechanism

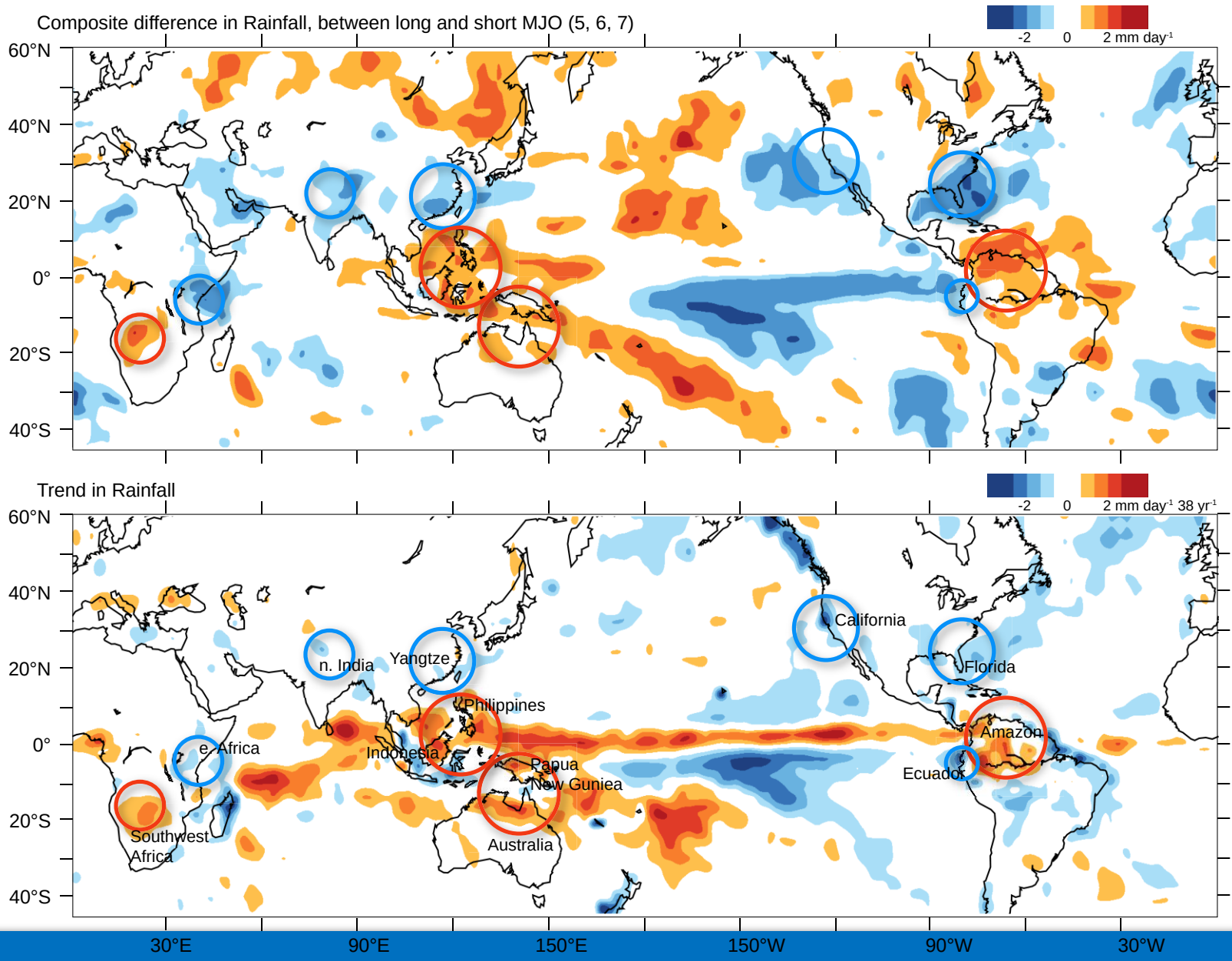
While the warm SST trend in the west Pacific prolongs the local convective activity, it also drives dry air subsidence over the Indian Ocean

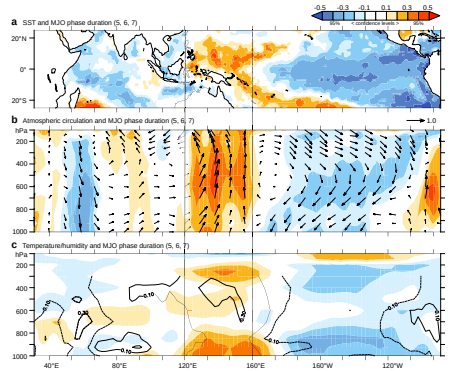
Humidity trends show increase over west Pacific



and (subsidence related) decrease over Indian Ocean

Impact on global rainfall patterns



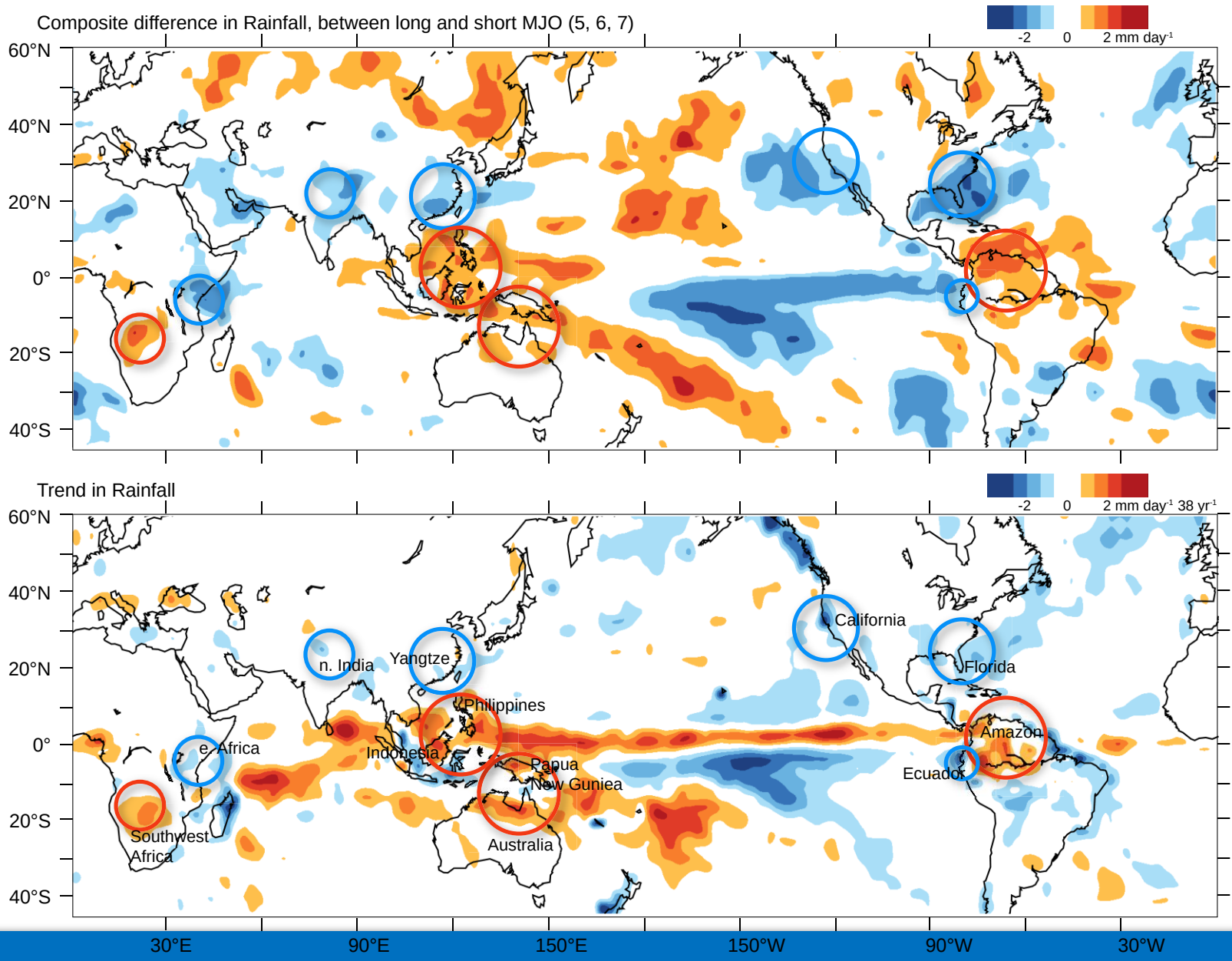


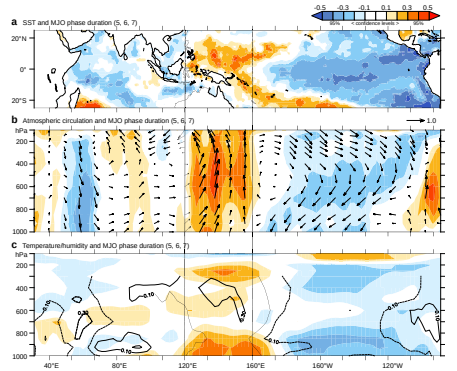
Increased rainfall over Maritime Continent, north Australia, Southwest Africa, Amazon

Drying over US, Central Pacific, Ecuador, East Africa, Yangtze in China and north India

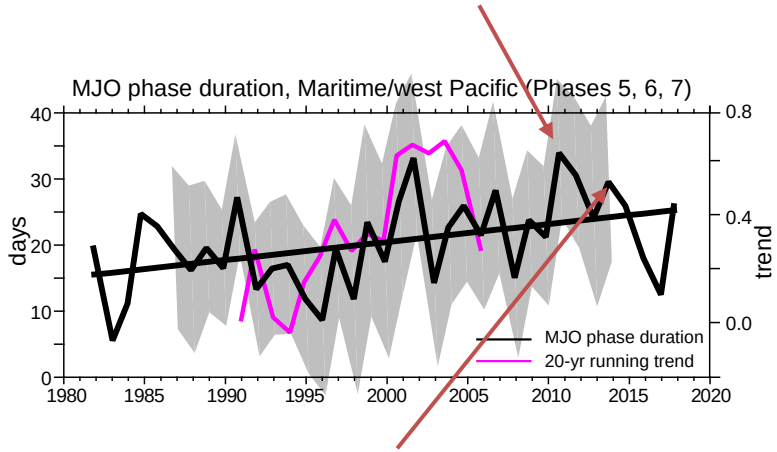
Indo-Pacific warming is not only changing the MJO but also these regional precipitation anomalies, either synergistically through the MJO or through independent pathways

Impact on global rainfall patterns





Indonesian floods and east African droughts
(2011, MJO p5/6/7 for 30 days)



California droughts
(2013–2014, MJO p5/6/7 for 25–28 days)

nature

Article | Published: 27 November 2019

Twofold expansion of the Indo-Pacific warm pool warps the MJO life cycle

M. K. Roxy ✉, Panini Dasgupta, Michael J. McPhaden, Tamaki Suematsu, Chidong Zhang & Daehyun Kim

Nature **575**, 647–651(2019) | Cite this article

Indo-Pacific warming warps the MJO, changing global rainfall patterns

1. **The Indo-Pacific warm pool is rapidly warming**

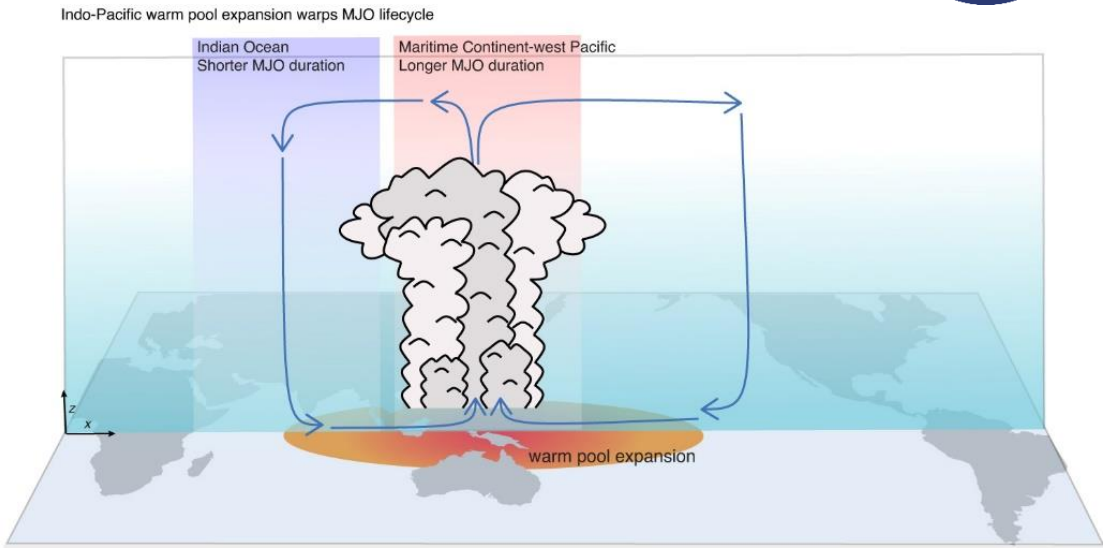
and expanding at the size of California every year (400,000 km^2)

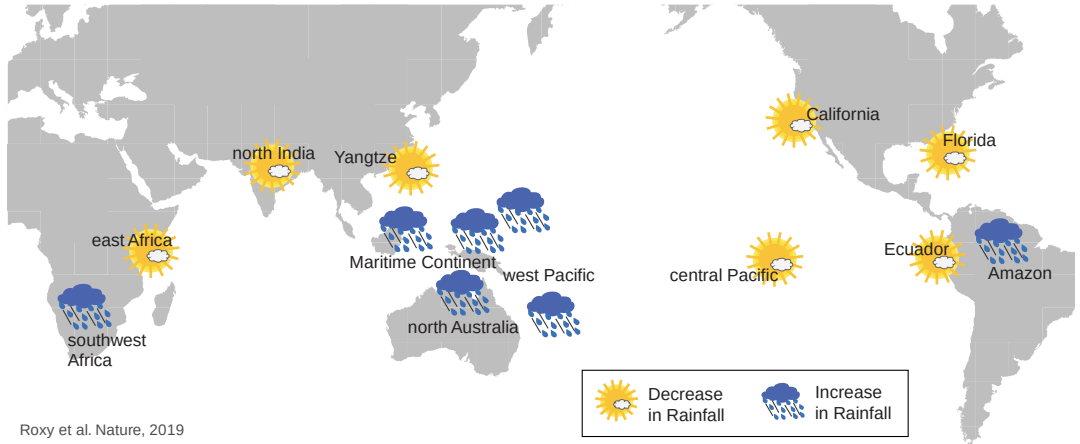
2. **This has changed the residence time of the MJO**
   - — shortened over Indian Ocean (3–4 days)
   - — prolonged over West Pacific (5–6 days)

3. **Thereby altering global rainfall patterns**

increased rainfall over Maritime Continent, north Australia, Southwest Africa, Amazon

drying over US, Central Pacific, Ecuador, East Africa, Yangtze in China and north India





Roxy et al. Nature, 2019

Roxy Mathew Koll[1], Panini Dasgupta[1], Michael J. McPhaden[2], Tamaki Suematsu[3], Chidong Zhang[2] & Daehyun Kim[4]

[1] Indian Institute of Tropical Meteorology | [2] PMEL, NOAA | [3] U. Tokyo | [4] U. Washington