Responses of the MJO to global warming: Impacts from tropical SST changes

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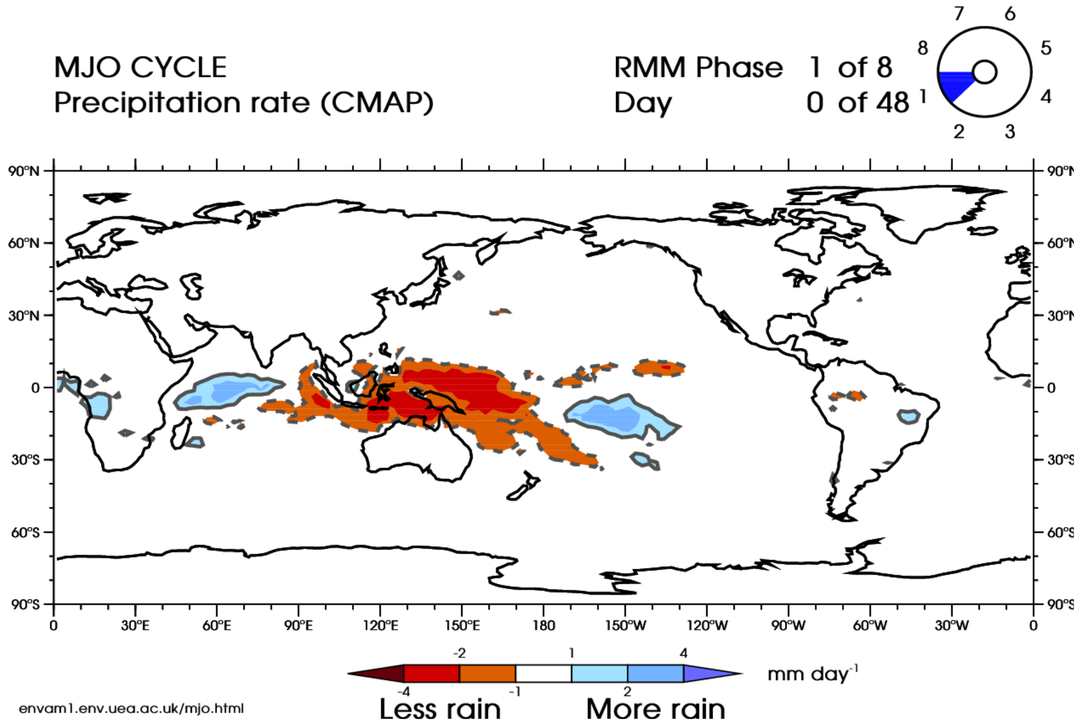
Madden-Julian oscillation (MJO)



Under global warming,

- Increased MJO precipitation
- Weakened MJO wind
- MJO propagate faster
- Eastward extension

➢ **Absolute warming**

➢ **Pattern of warming**

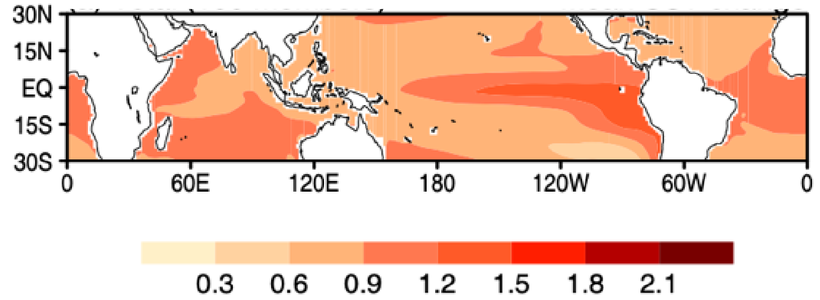
→ What are the possible warming patterns?

→ How different warming patterns impact the MJO?

CESM2 Large Ensemble

- 100 ensemble members, 1° resolution
- Boreal winter (November-April)
- HIST (1981-2010) vs. SSP370 (2071-2100)
- Cluster analysis

Three projections of mean SST changes



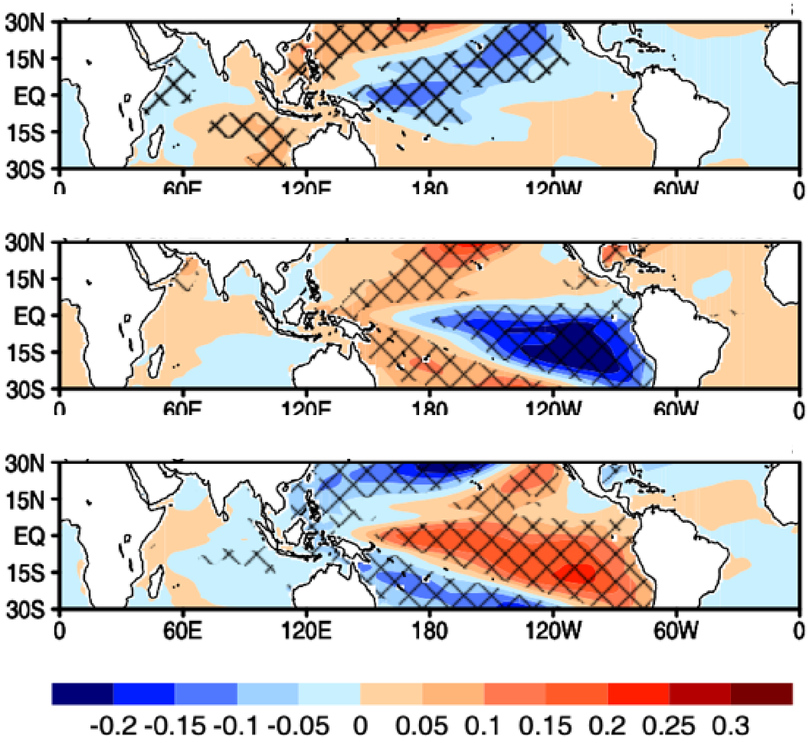
Total ensemble mean (100 members)
SST changes (SSP370 minus HIST)
El Niño-like warming pattern

k-mean cluster analysis

Moderate
(35 members)

Weak
(31 members)

Strong
(34 members)



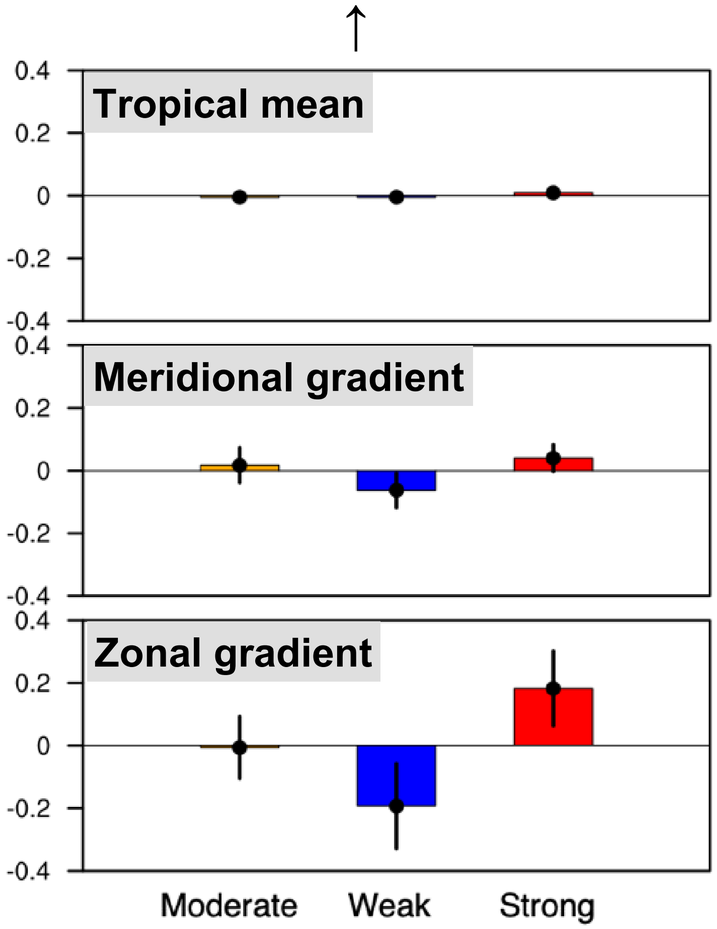
Three clusters (anomalous changes relative to the total)

* Cross-hatching indicates 95% confidence level according to a two-tailed Student's t-test between each cluster and the total.

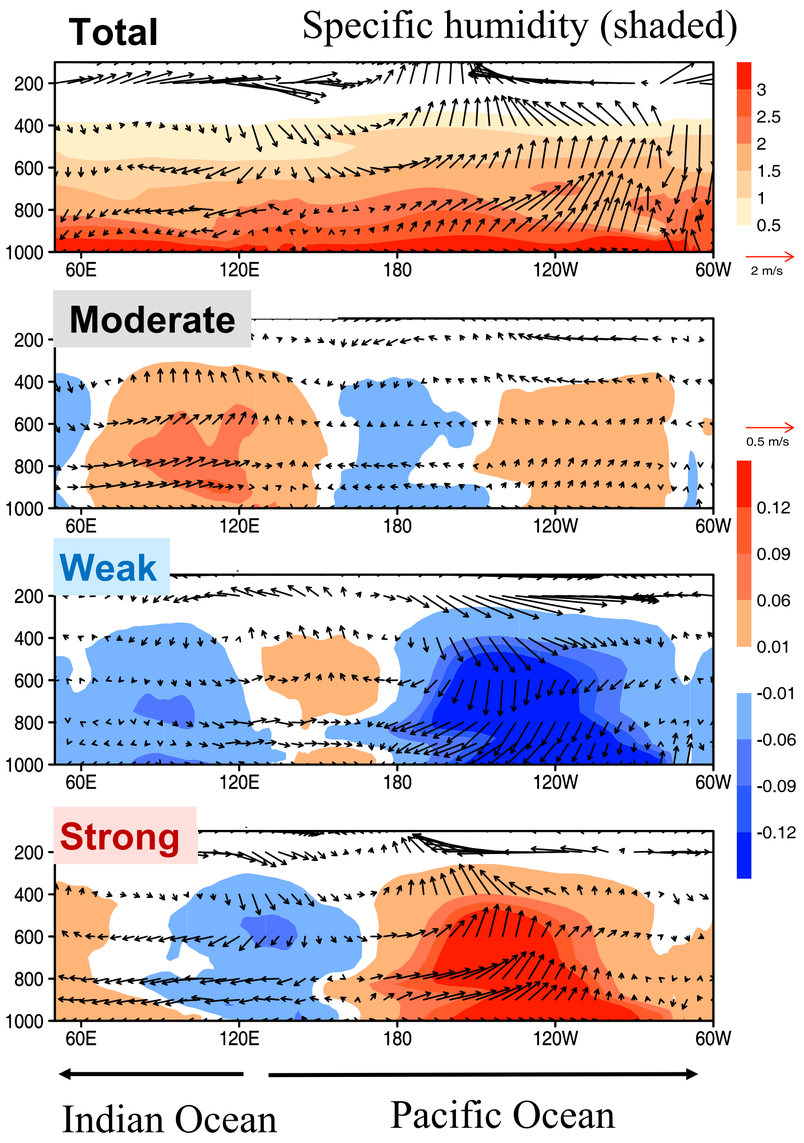
* Justified by Elbow method and Silhouette coefficient.

Impacts on the mean state

absolute SST change is
almost the same as the total



→ the patterns of warming are different, especially the zonal SST gradient.

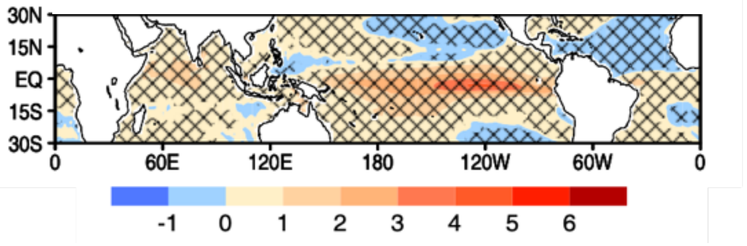


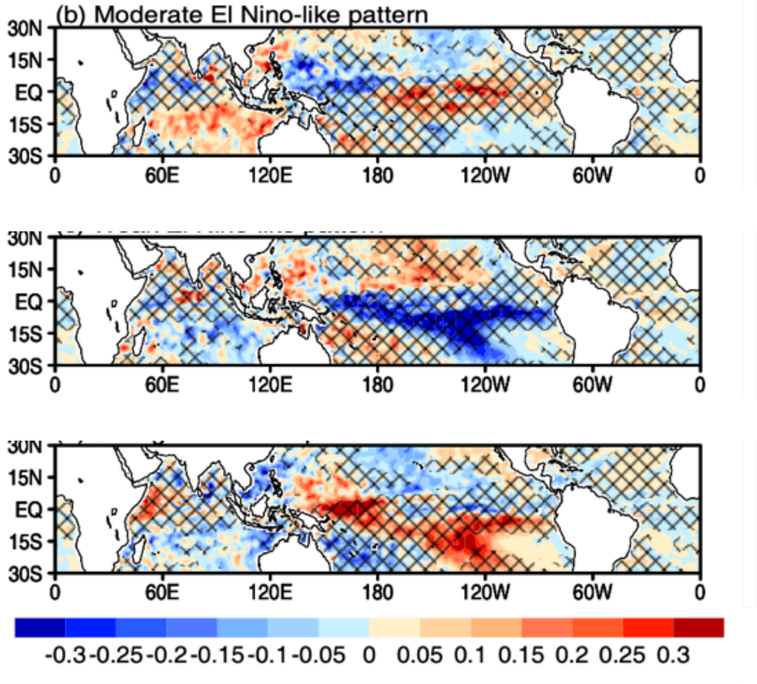
*averaged from 15°S-5°N

Impact on
the MJO and
its teleconnections?

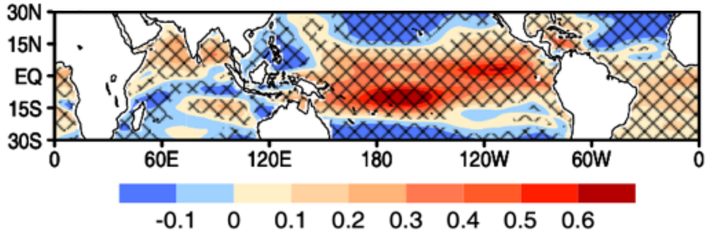
Impacts on MJO amplitude

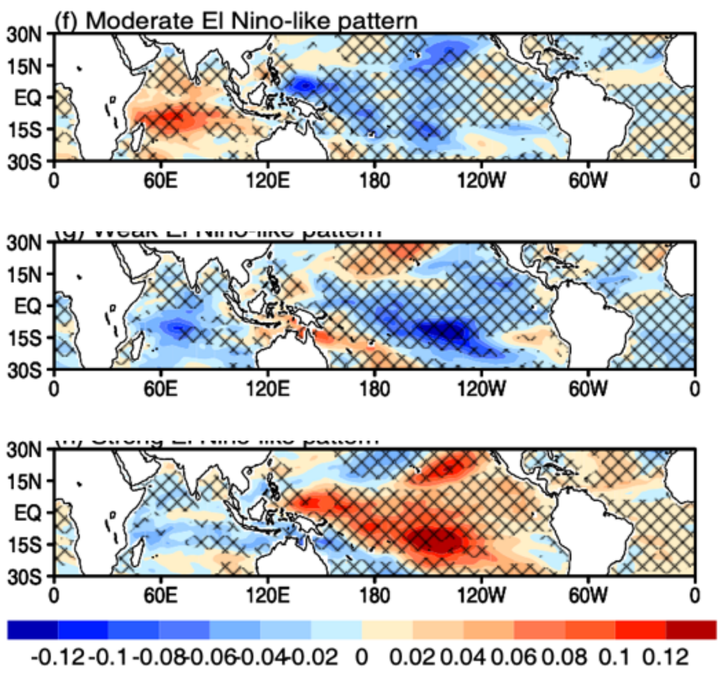
MJO precipitation





MJO wind





→ MJO rainfall: increase
MJO wind: increase over Pacific, but decrease over Indian Ocean

Moderate
- increase: equatorial eastern Pacific
- decrease: western Pacific

Weak
- increase: ITCZ region
- decrease: Indian Ocean and central-eastern Pacific

Strong
Generally increase, especially in the Pacific Ocean

Alpha (α): Efficiency with which a diabatic heating anomaly can moisten the tropical atmosphere through vertical advection under WTG balance

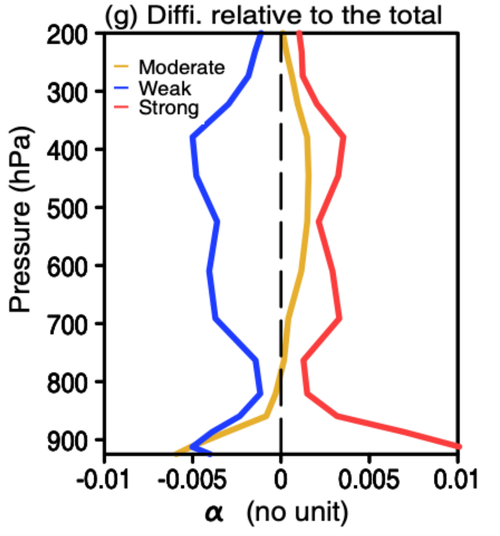
$$\alpha = -L_v \left(\frac{\frac{\partial q}{\partial p}}{\frac{\partial s}{\partial p}} \right)$$

Vertical moisture gradient

Vertical dry static energy gradient

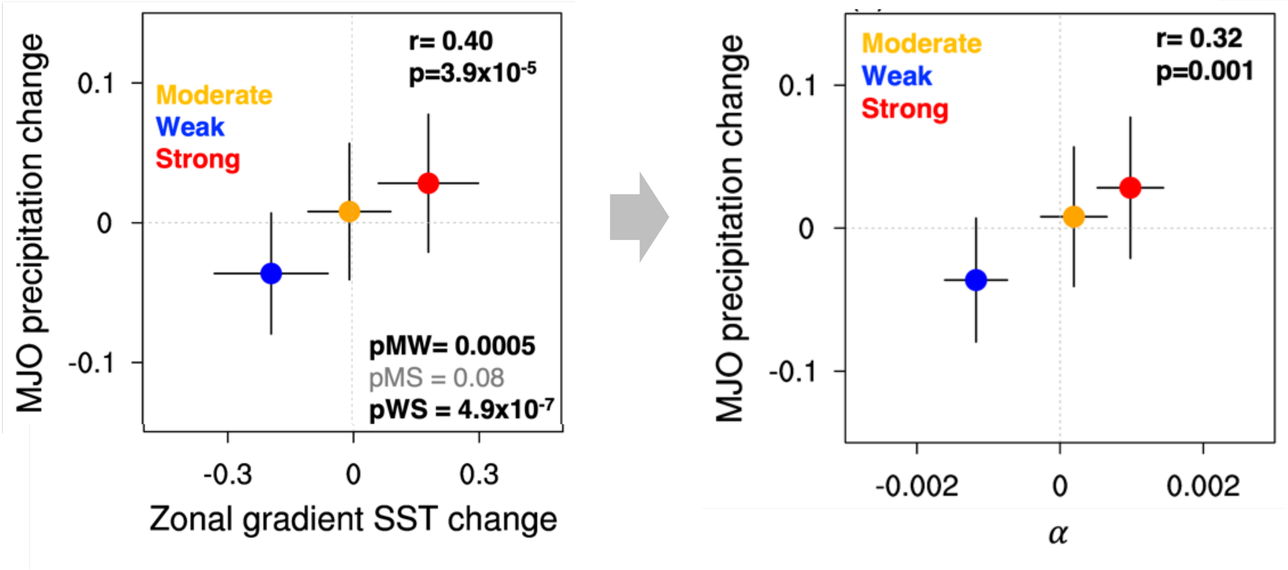
Latent heat of vaporization

Also see Bui and Maloney (2019, J. Climate)



- increase: strong El Niño–like pattern
- decrease: weak El Niño–like pattern

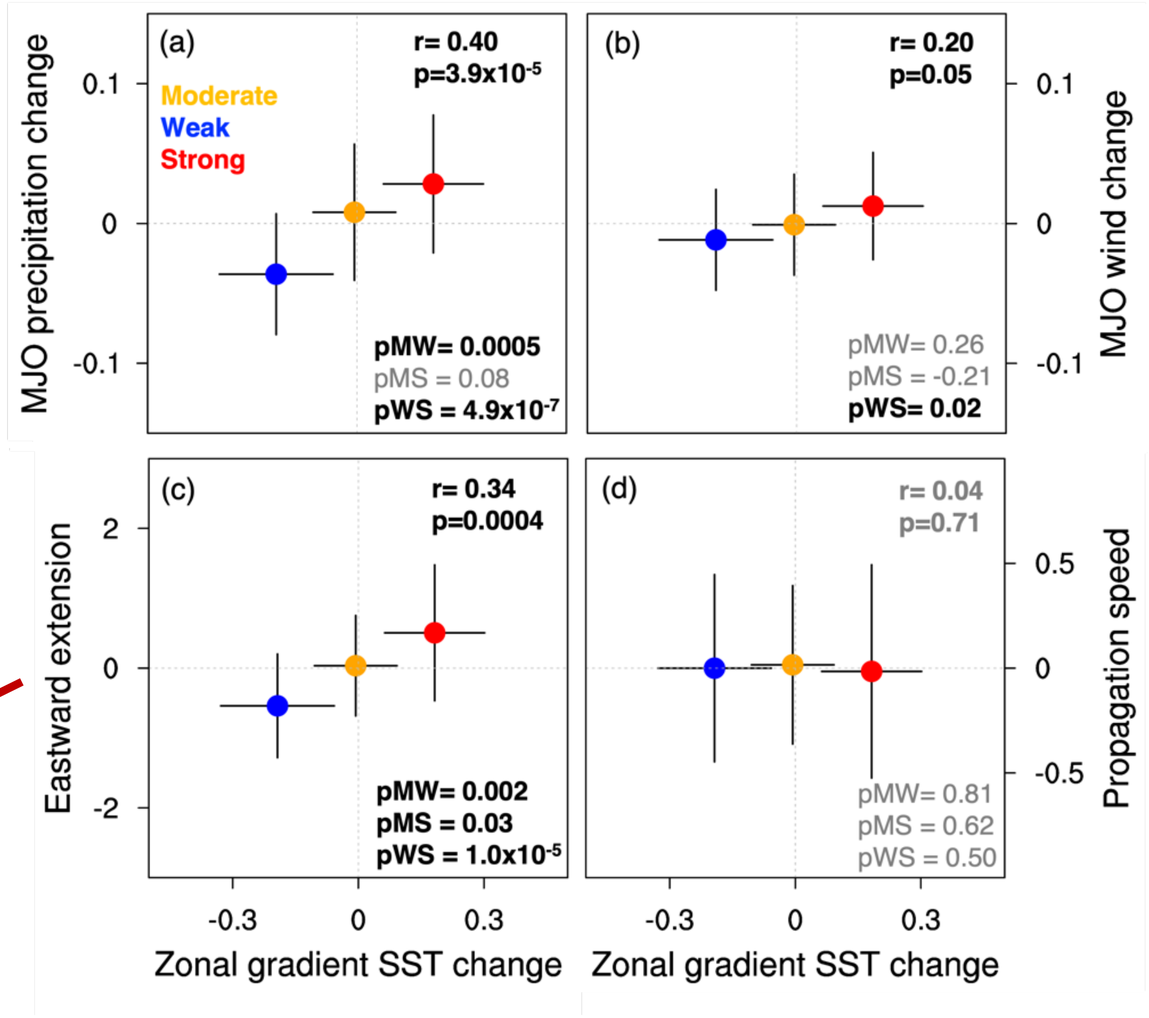
❖**Increased α**
→ stronger vertical moisture advection
→ favor MJO activity.



➢ Changes in α relative to precipitation all fall along a straight line, offset from the origin.

➢ Contribution of moisture changes is greater than dry static energy change.

Impacts on MJO characteristics

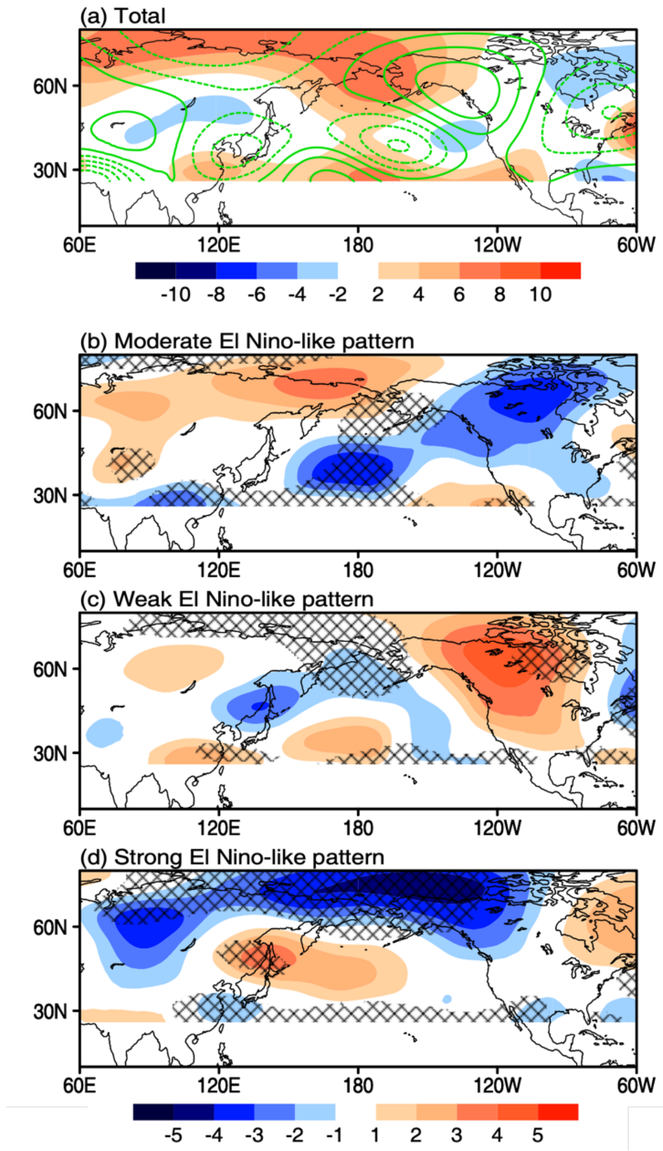


→ travel farther eastward into the central and eastern Pacific with a zonal SST gradient like the strong El Niño–like

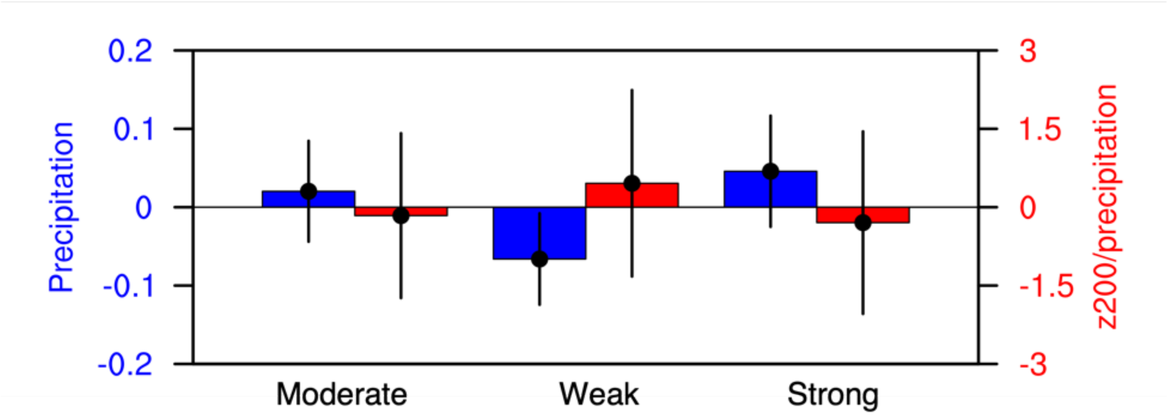
→ uncertain

Impacts on MJO teleconnections

MJO-induced z200 variability



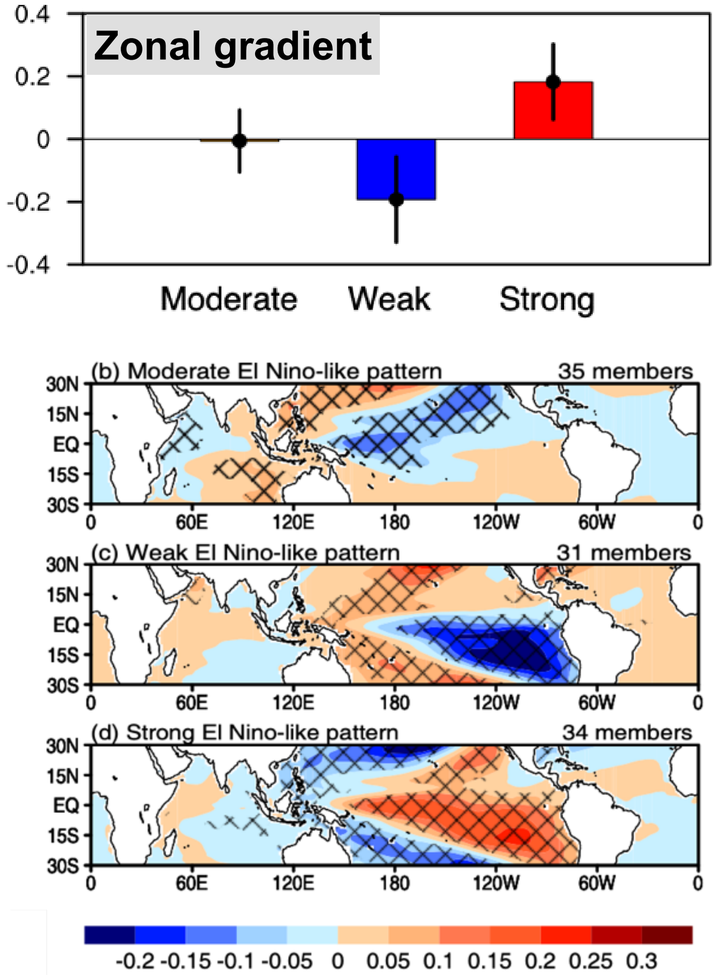
- positive: moderate & weaker El Niño–like patterns
- negative: stronger El Niño–like pattern over the West Coast of the U.S.
- uncertain between the clusters



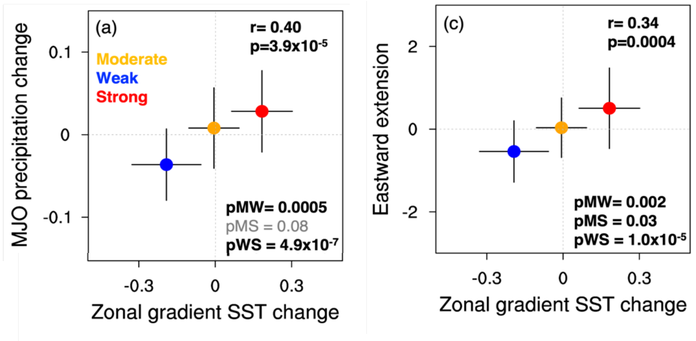
➢ **Cluster-mean**: anomalous MJO forcing to extratropical will be decreased relative to the total in the moderate and strong El Niño–like patterns.

Conclusions

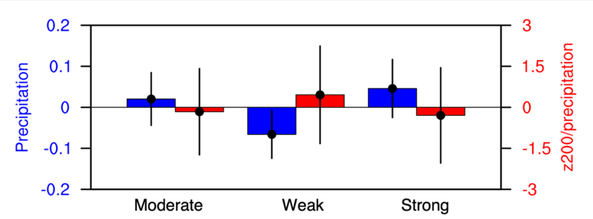
- Under global warming in the SSP370 scenario, three potential warming patterns were classified.



- MJO amplitude and eastward extension significantly increase in the stronger El Niño–like pattern and decrease in the weaker El Niño–like pattern relative to the total.



- Changes to MJO propagation speed, and MJO's teleconnection are uncertain, given the large internal climate variability.



Bui et al., 2024: Responses of the Madden–Julian Oscillation to Global Warming: Impacts from Tropical Sea Surface Temperature Changes. *J. Climate*, **37**, 605–617. https://doi.org/10.1175/JCLI-D-23-0213.1

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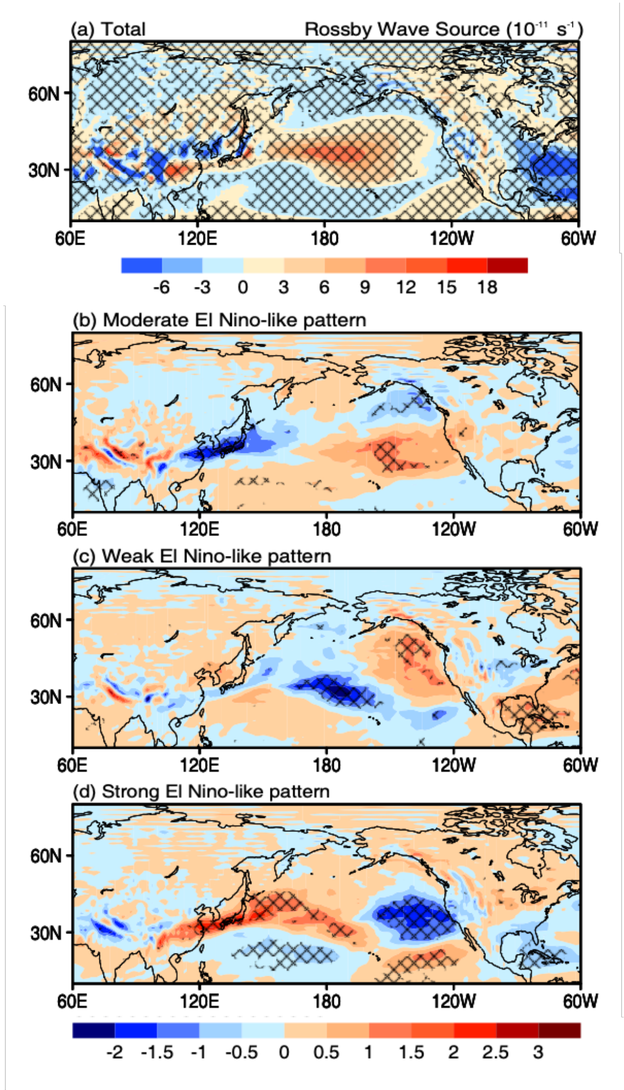
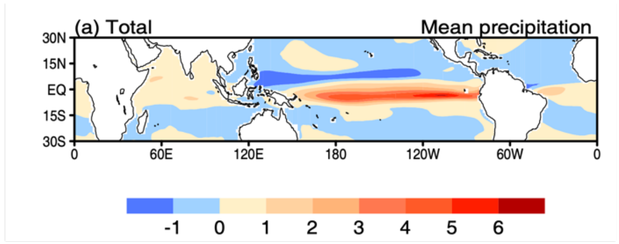
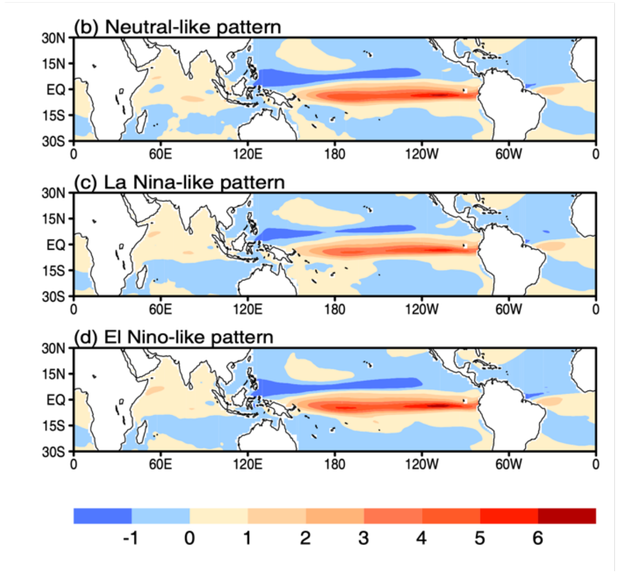
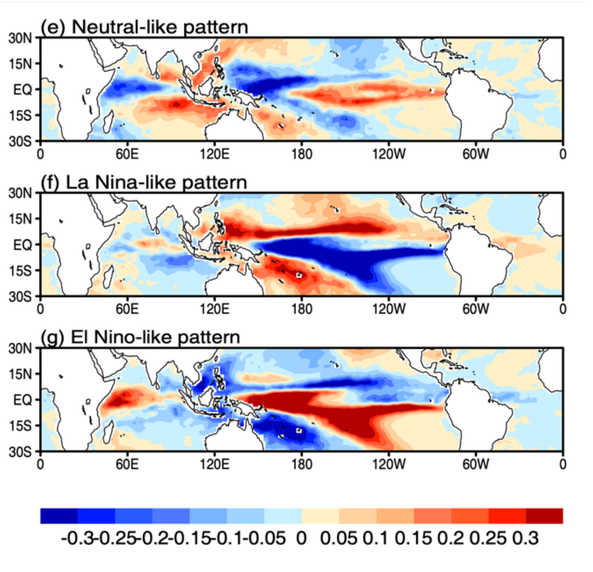

(a) Total
Rossby Wave Source (10^{-11} s^{-1})
60N
30N
60E
120E
180
120W
60W
-6 -3 0 3 6 9 12 15 18
(b) Moderate El Nino-like pattern
(c) Weak El Nino-like pattern
(d) Strong El Nino-like pattern
-2 -1.5 -1 -0.5 0 0.5 1 1.5 2 2.5 3

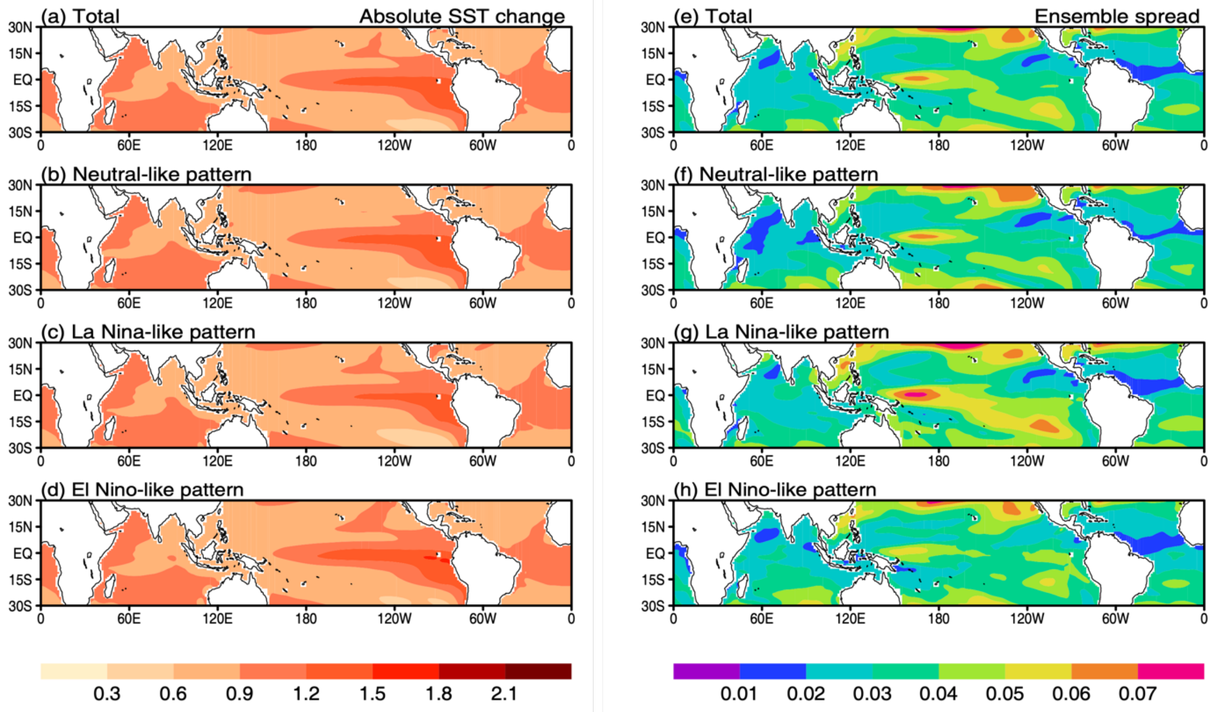


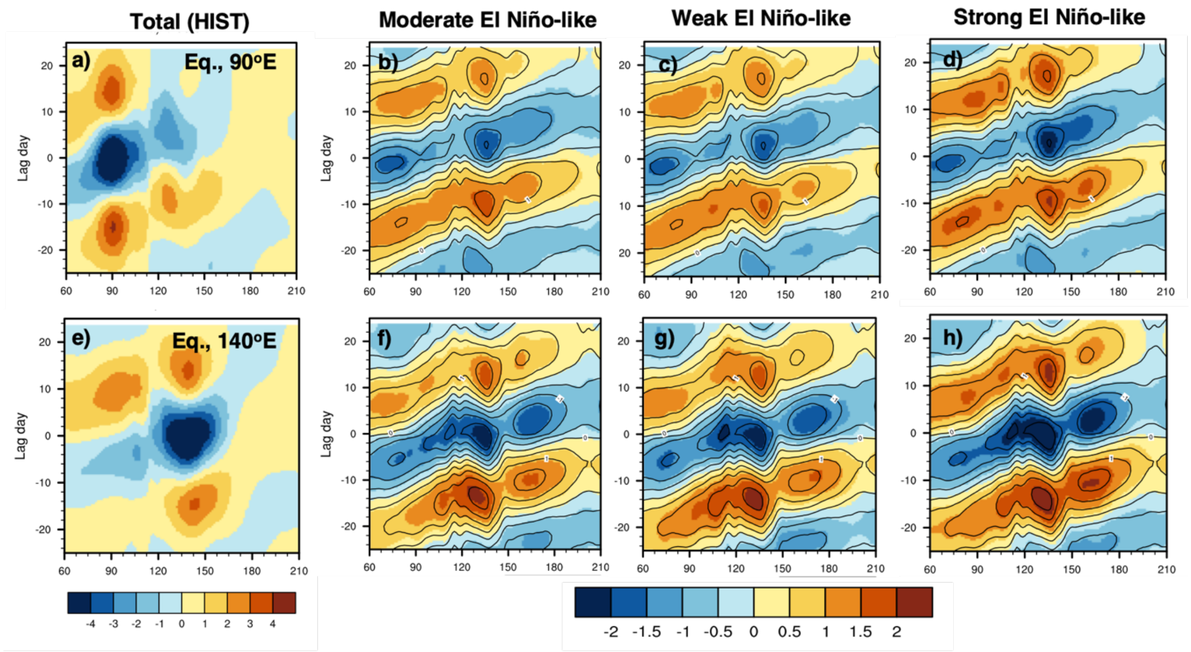
Absolute change

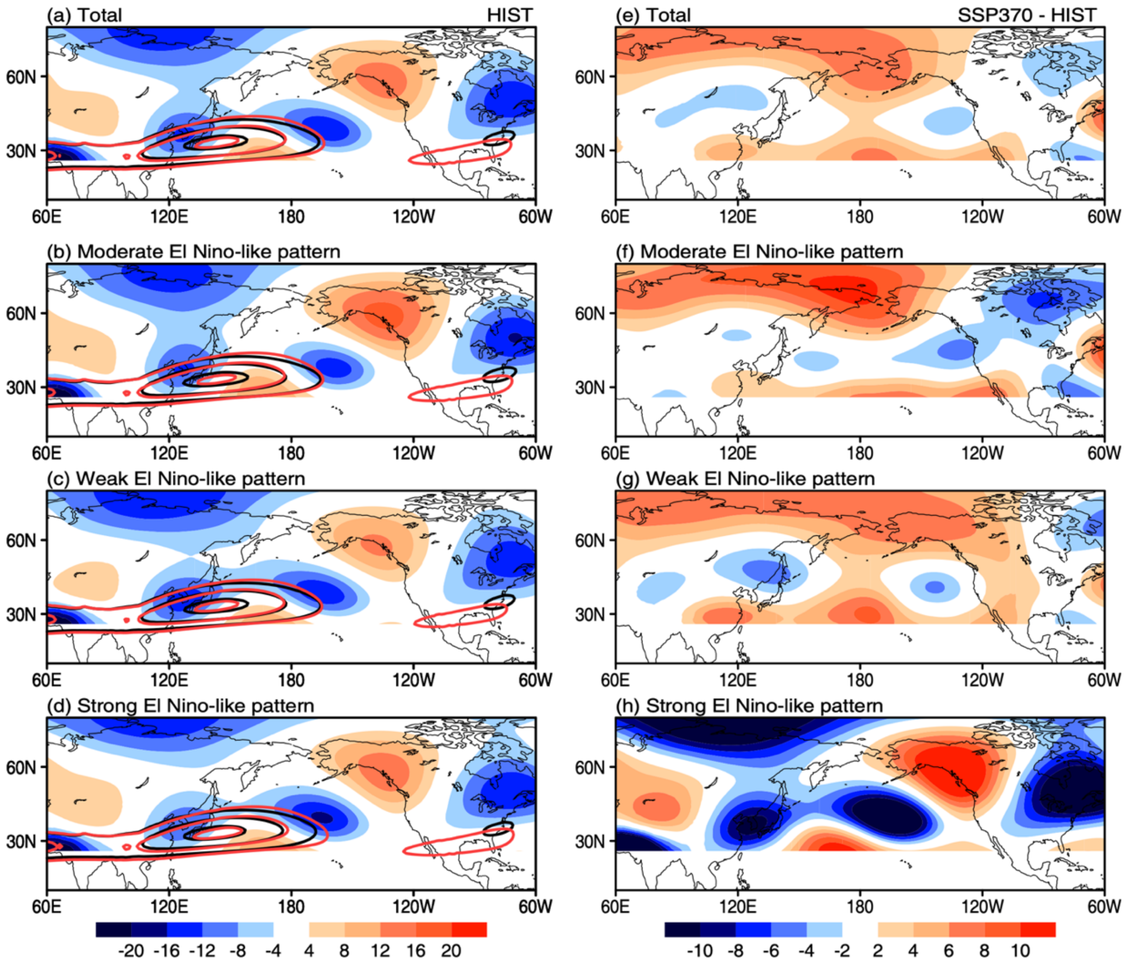


Deviation from the total




(a) Total
Absolute SST change
(b) Neutral-like pattern
(c) La Nina-like pattern
(d) El Nino-like pattern
30N
15N
EQ
15S
30S
0
60E
120E
180
120W
60W
0.3
0.6
0.9
1.2
1.5
1.8
2.1
(e) Total
Ensemble spread
(f) Neutral-like pattern
(g) La Nina-like pattern
(h) El Nino-like pattern
0.01
0.02
0.03
0.04
0.05
0.06
0.07


Total (HIST)
Moderate El Niño-like
Weak El Niño-like
Strong El Niño-like
a) Eq., 90°E
b)
c)
d)
e) Eq., 140°E
f)
g)
h)
Lag day
60 90 120 150 180 210
20 10 0 -10 -20
-4 -3 -2 -1 0 1 2 3 4
-2 -1.5 -1 -0.5 0 0.5 1 1.5 2


(a) Total
HIST
(b) Moderate El Nino-like pattern
(c) Weak El Nino-like pattern
(d) Strong El Nino-like pattern
(e) Total
SSP370 - HIST
(f) Moderate El Nino-like pattern
(g) Weak El Nino-like pattern
(h) Strong El Nino-like pattern
60N
30N
60E
120E
180
120W
60W
-20 -16 -12 -8 -4 4 8 12 16 20
-10 -8 -6 -4 -2 2 4 6 8 10