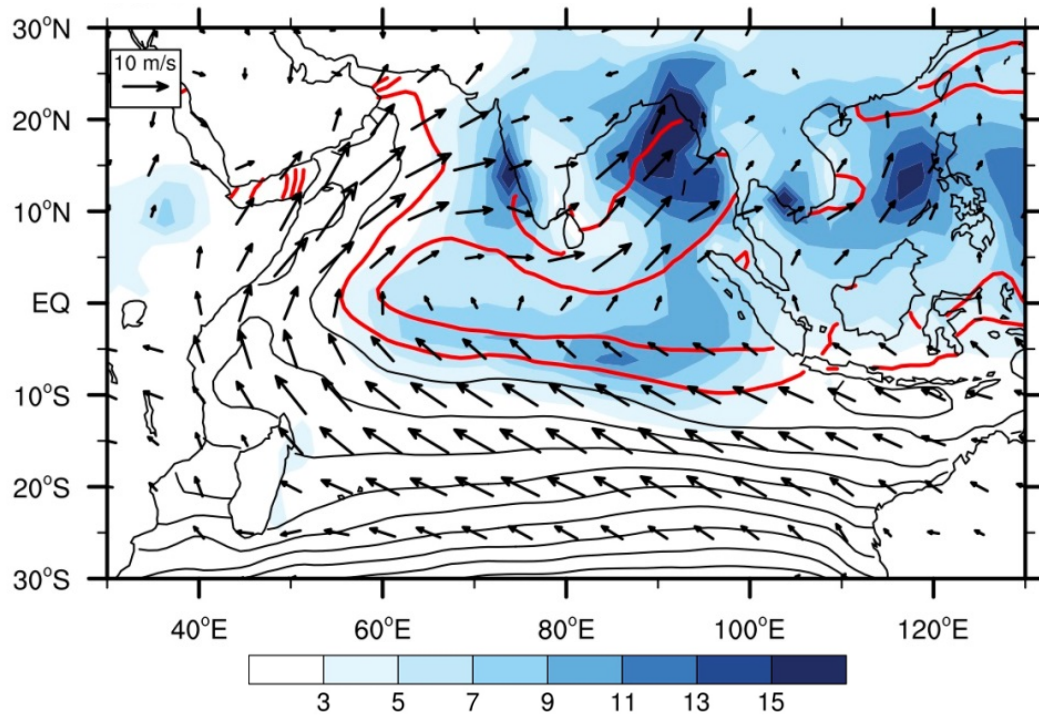


# Summer monsoon variability & predictability: The rise of the Indian Ocean

Shang-Ping Xie

Scripps Institution of Oceanography, UCSD



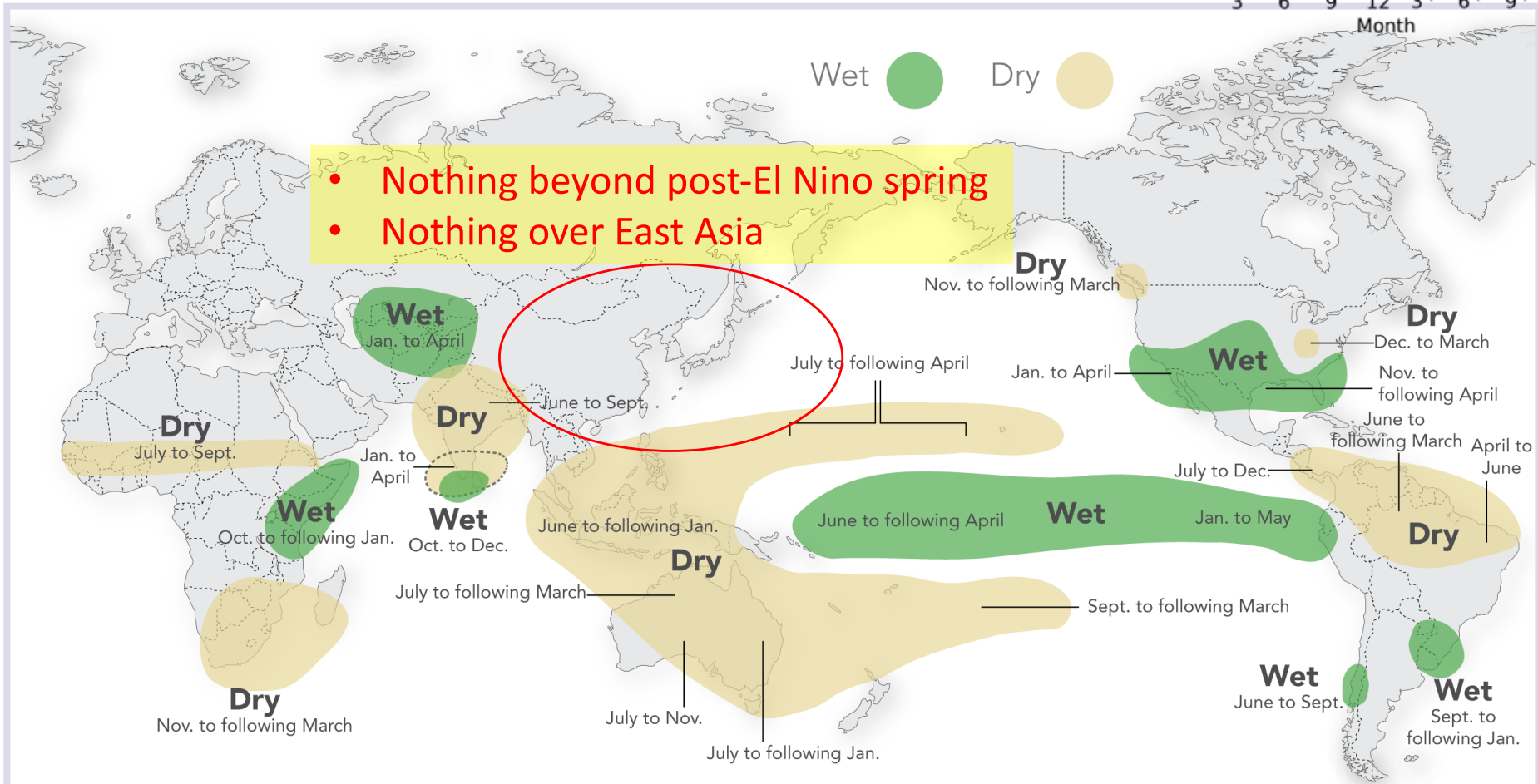
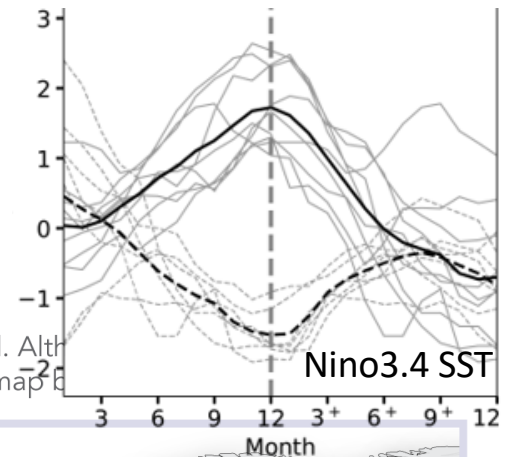
JJA SST ( $\geq 28^\circ\text{C}$ ), precip (mm/day) & sfc wind



- S/E Asian monsoon variability
- Indo-western Pacific capacitor (IPOC)
- 2020 “torrential Meiyu” vs. 1998
- Reflections on prediction

# El Niño and Rainfall

El Niño conditions in the tropical Pacific are known to shift rainfall patterns in many different parts of the world. Although one El Niño to the next, the strongest shifts remain fairly consistent in the regions and seasons shown on the map.



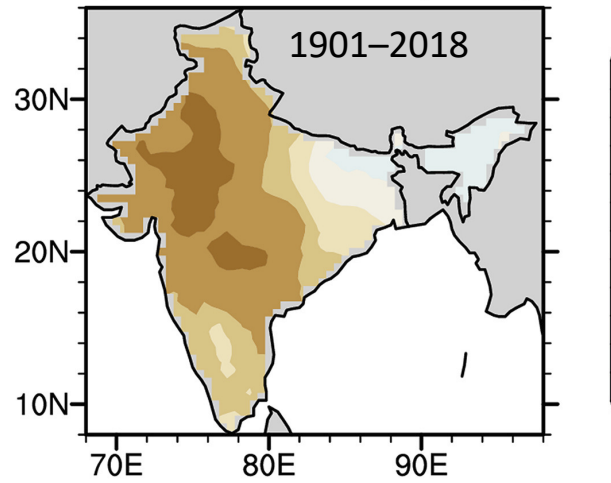
- Nothing beyond post-El Nino spring
- Nothing over East Asia

For more information on El Niño and La Niña, go to: <http://iri.columbia.edu/enso/>

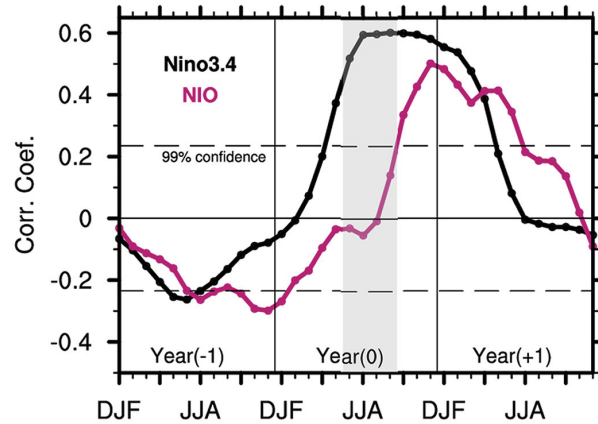
Sources:

1. Ropelewski, C. F., and M. S. Halpert, 1987: Global and regional scale precipitation patterns associated with the El Niño Southern Oscillation. *Mon. Wea. Rev.*, 115, 1606-1626;
2. Mason and Goddard, 2001. Probabilistic precipitation anomalies associated with ENSO. *Bull. Am. Meteorol. Soc.* 82, 619-638

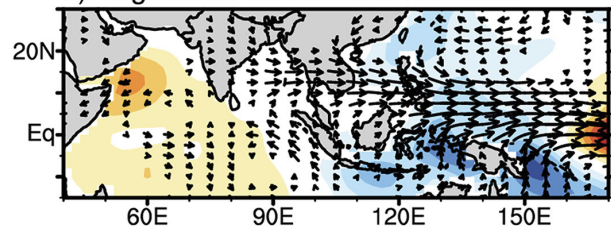
a) JJAS Rainfall EOF1 [31.4%]



c) JJAS Rainfall PC1 [31.4%]



e) Regression on JJA Niño-3.4 index

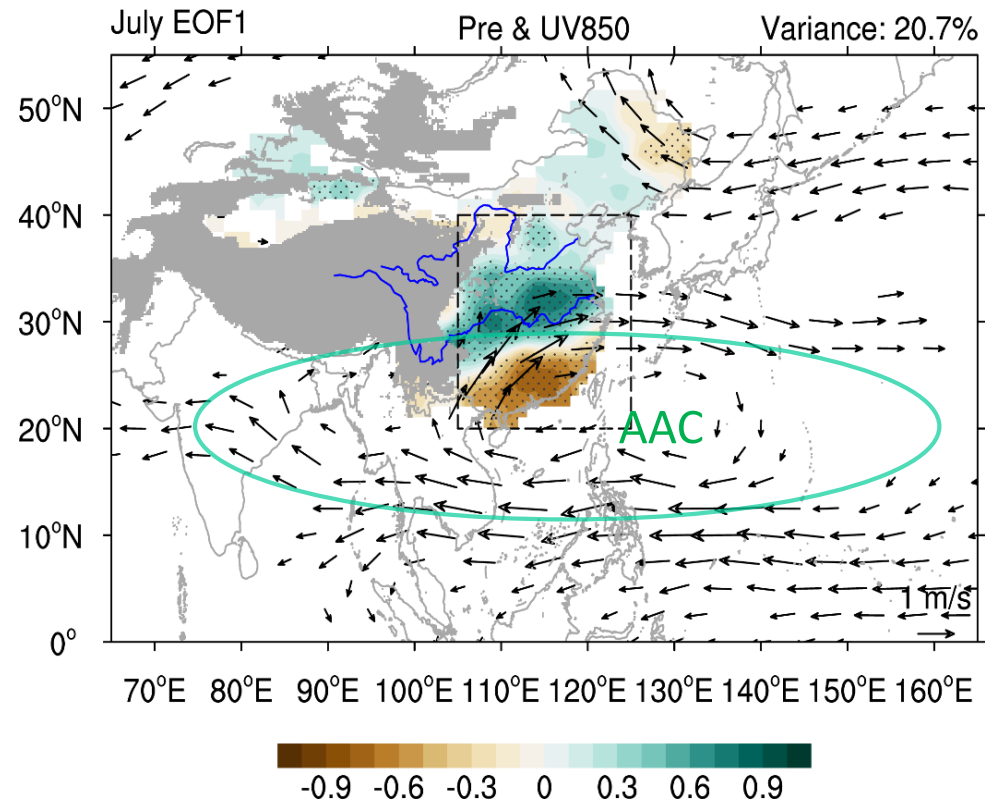


850 hPa wind

## Indian monsoon variability

- EOF1 (All India Rainfall): concurrent ENSO
- EOF2: post-ENSO summer

Anomalous anticyclone (AAC)



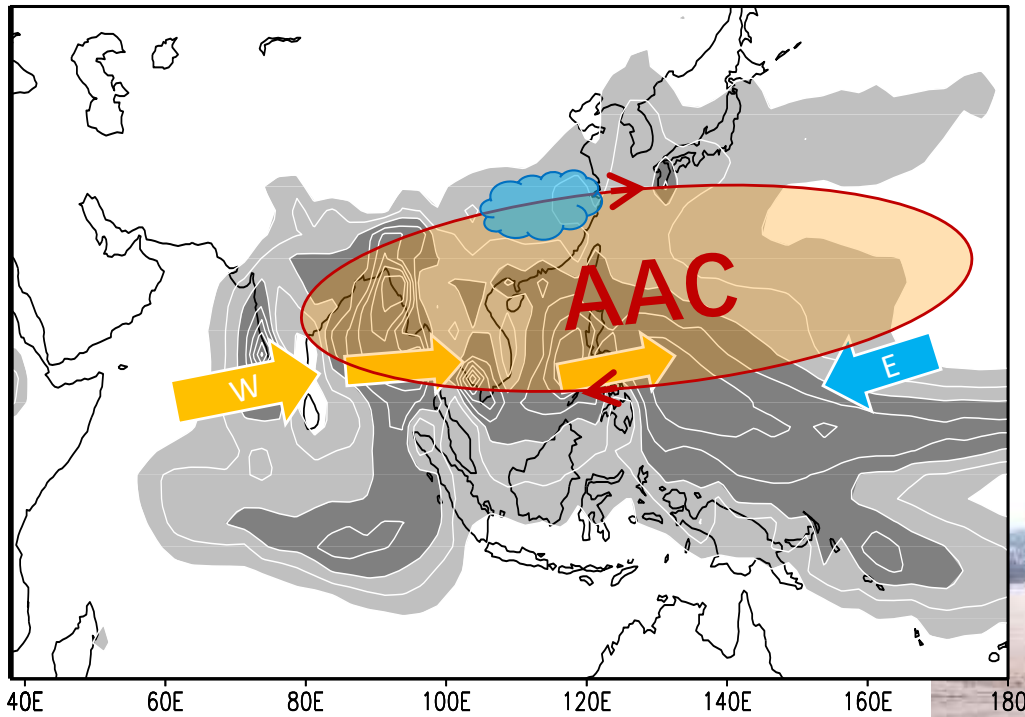
EOF1 of July rainfall variability over eastern China & 850 hPa wind velocity regression. Correlation w/ ND(-1)J Nino3.4 =0.3 for 1951-2020.



# Anomalous anticyclonic circulation (AAC) as a mode of monsoon variability

Barotropic energy conversion

$$CK \approx 2\overline{u'^2} \left( -\frac{\partial \bar{u}}{\partial x} \right)$$



X. Wang et al. 2021, *J Clim.*



Great Yangtze Flood of 1998

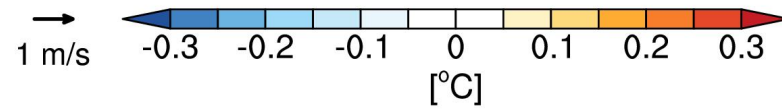
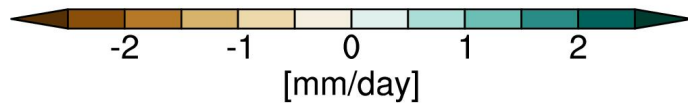
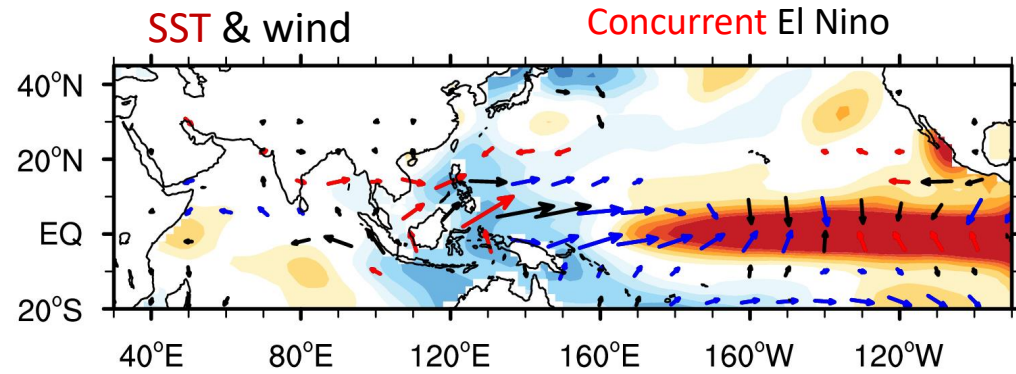
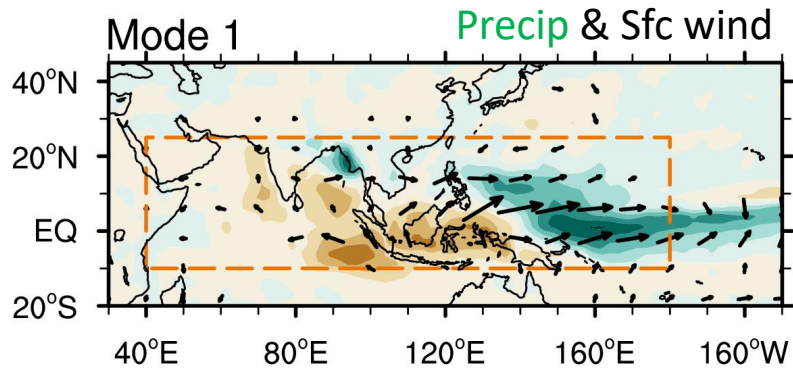


Record rainfall of 560 mm in Wuhan for week of 6/30-7/6/2016)



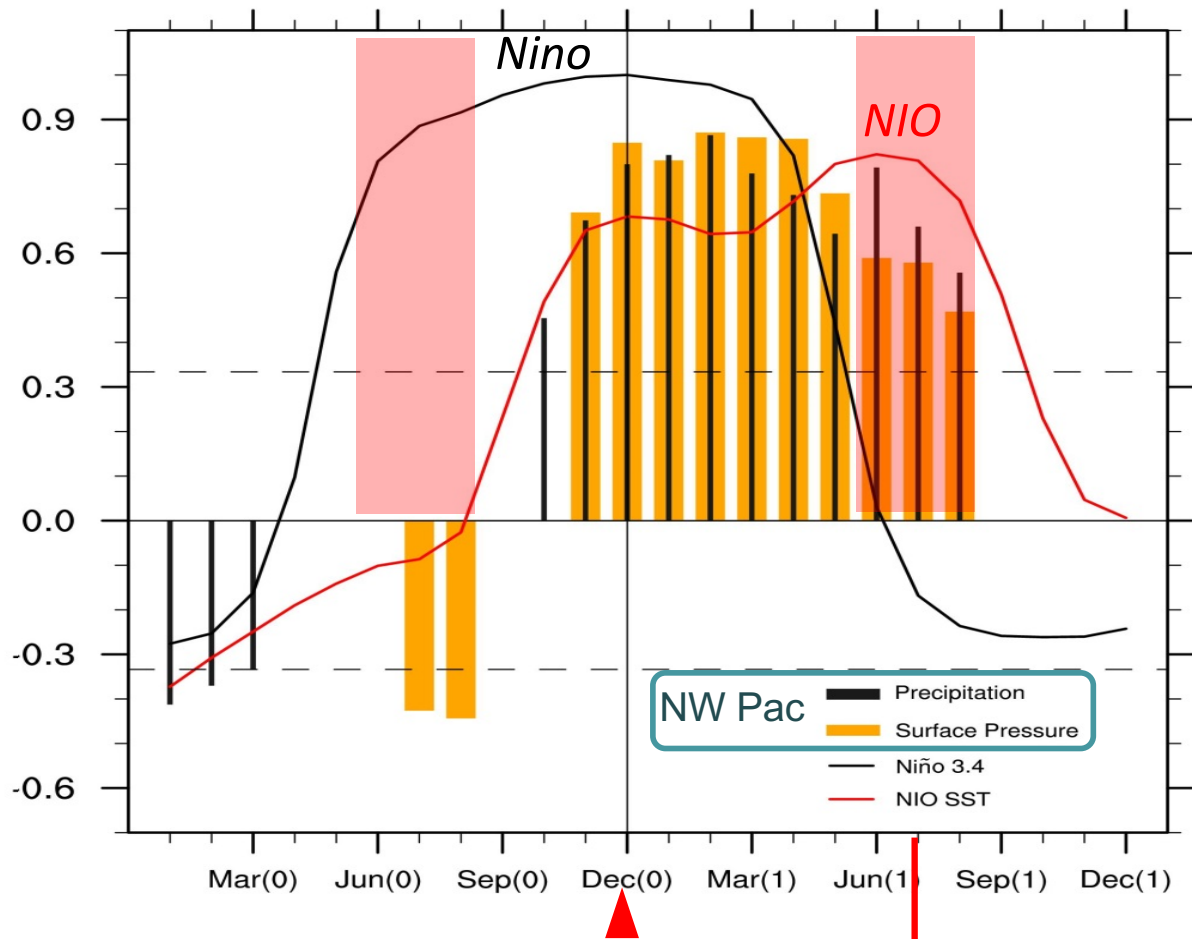
Wuhan, 7/8/2020

# JJA Precip EOF over Indo-W Pac

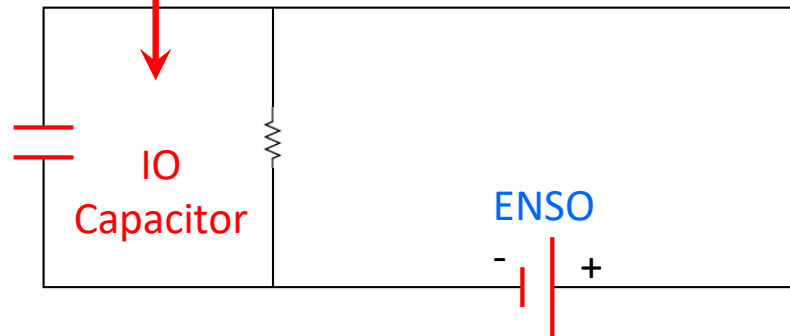


Rainfall EOF	PC1
JJA Nino 3.4	0.81
ND(-1)J Nino 3.4	
JJA NIO	

*How is mode 2 related to ENSO?*



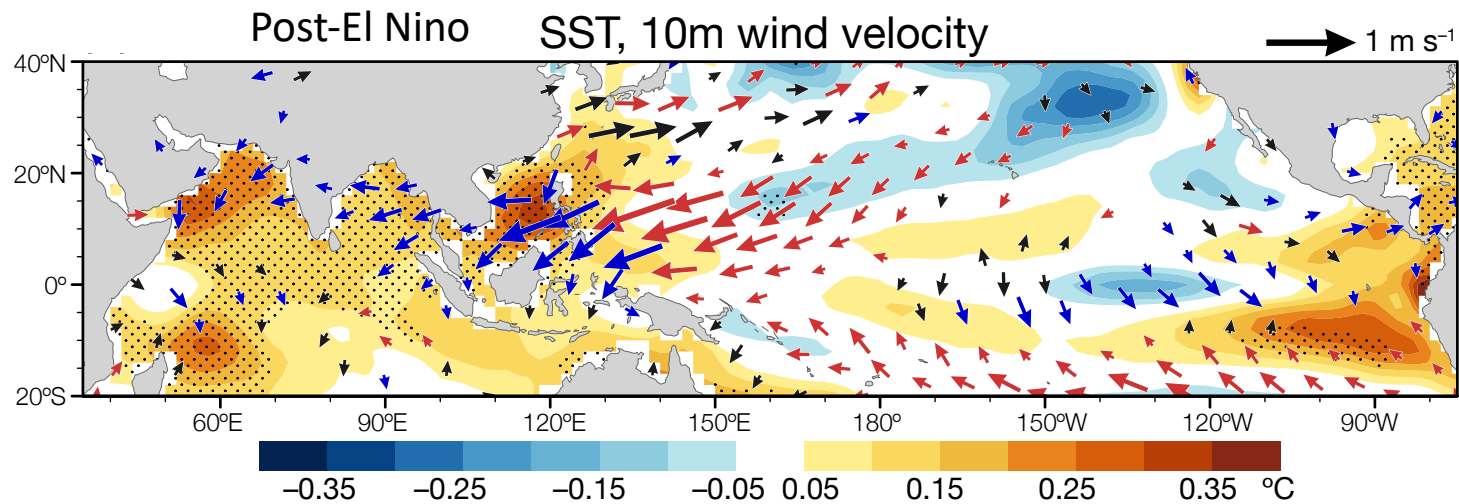
Indian Ocean warming persists through JJA(1) and could exert climatic influences after El Nino has dissipated.



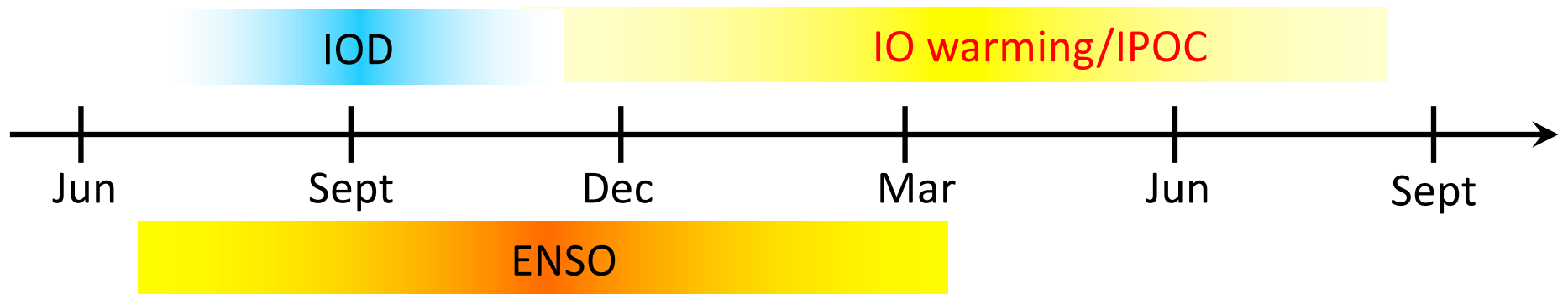
Xie et al., 2009: Indian Ocean capacitor effect on Indo-western Pacific climate during the summer following El Nino. *J. Climate*, 22, 730-747.

# Indo-western Pacific ocean capacitor (IPOC)

IO warming → NW Pacific anticyclone → Easterly anomalies  
Positive feedback  
Reduced SW wind



## Indian Ocean modes

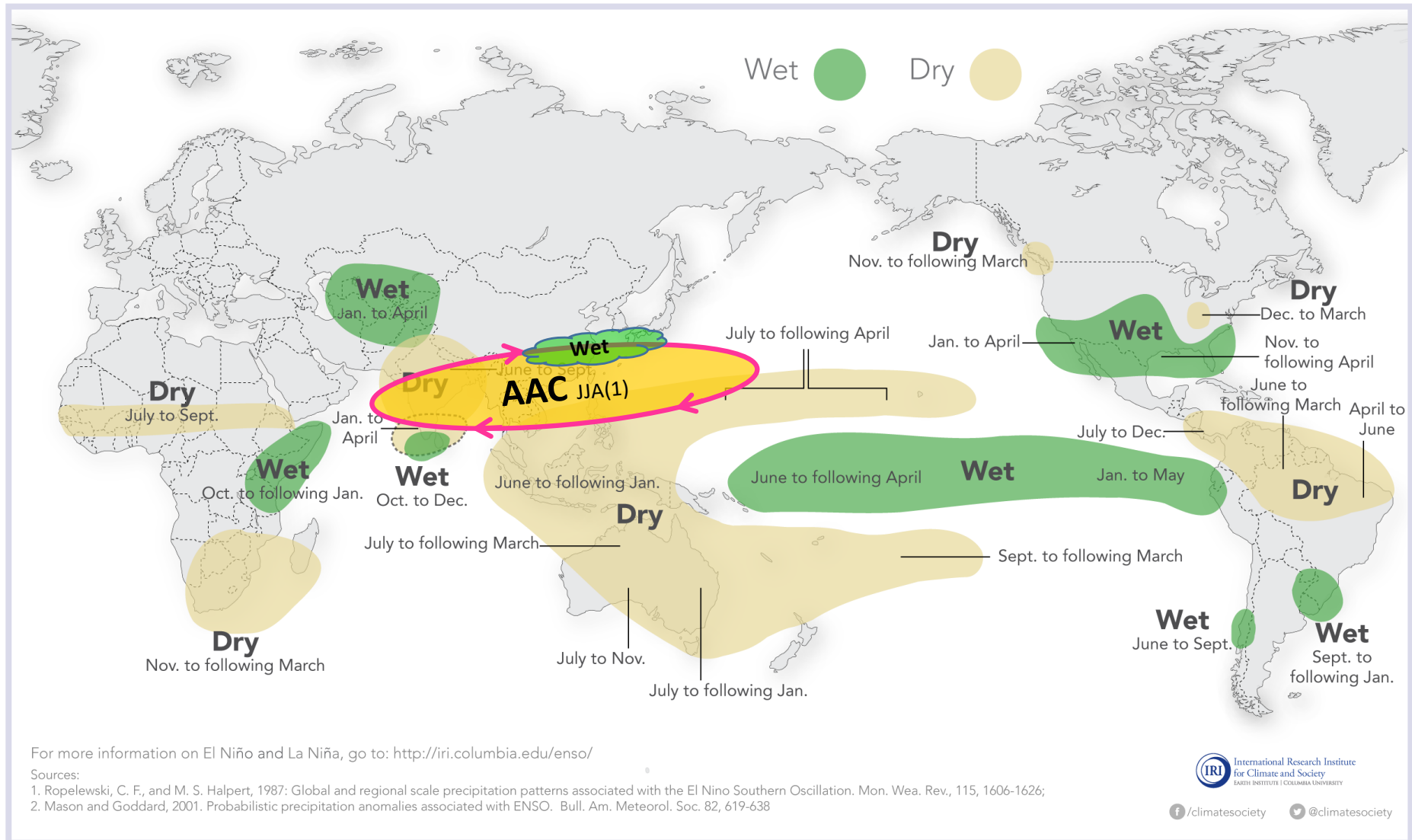






# El Niño and Rainfall

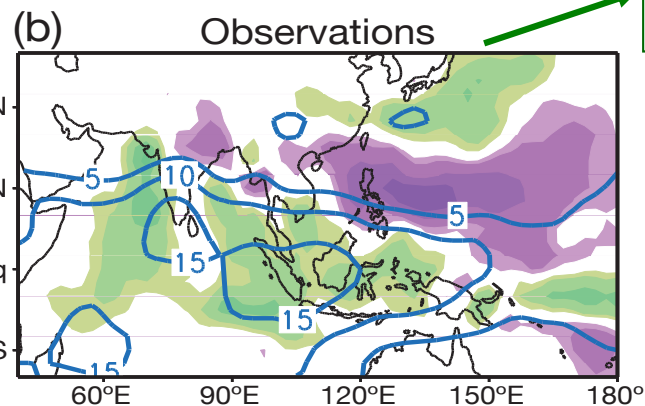
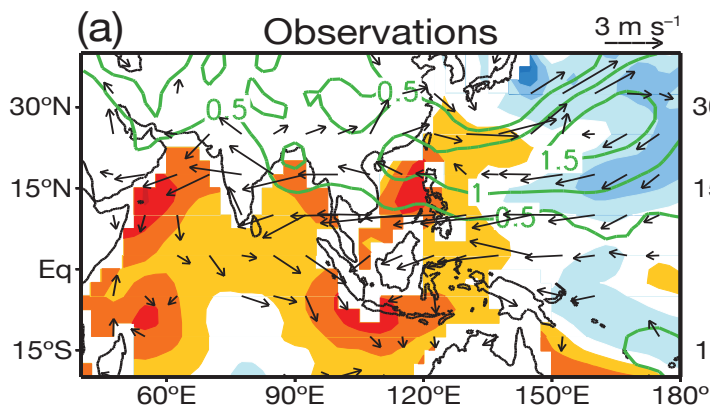
El Niño conditions in the tropical Pacific are known to shift rainfall patterns in many different parts of the world. Although they vary somewhat from one El Niño to the next, the strongest shifts remain fairly consistent in the regions and seasons shown on the map below.



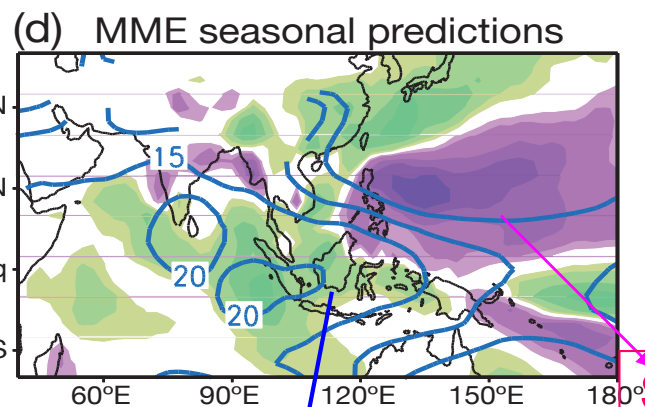
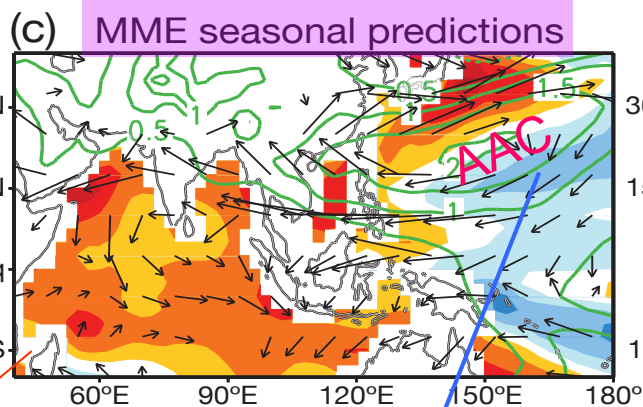
# Composites of post-El Niño summers (1983, 92 & 98)

SST (color), SLP (contours) & 850hPa wind

Precip (color), & Trop temp



Enhanced Meiyu



Suppressed rainfall

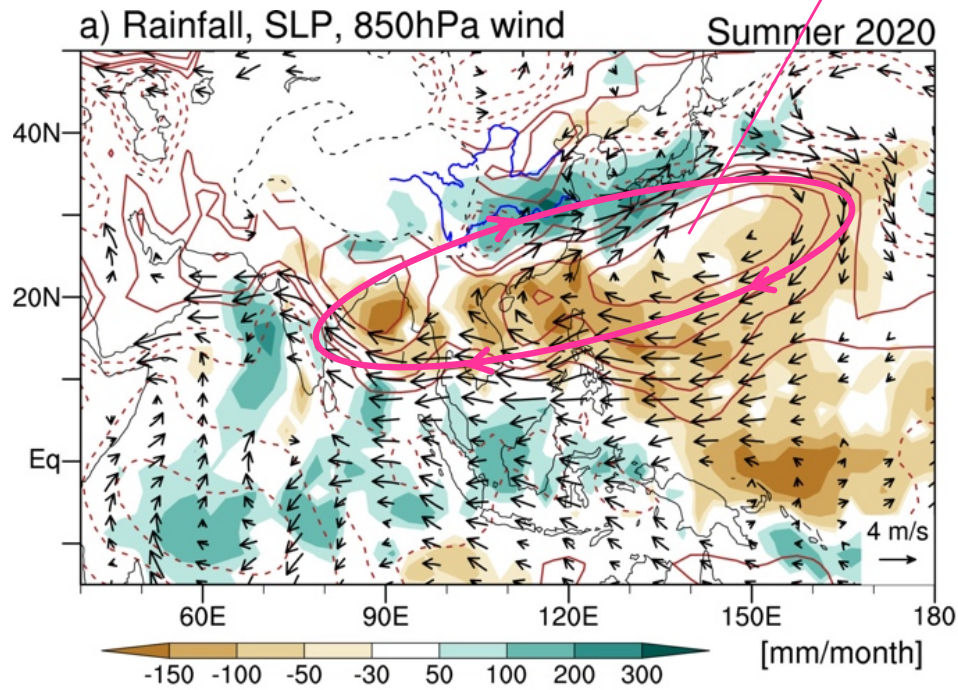
IO warming

SST cooling

Kelvin Wave in trop temp



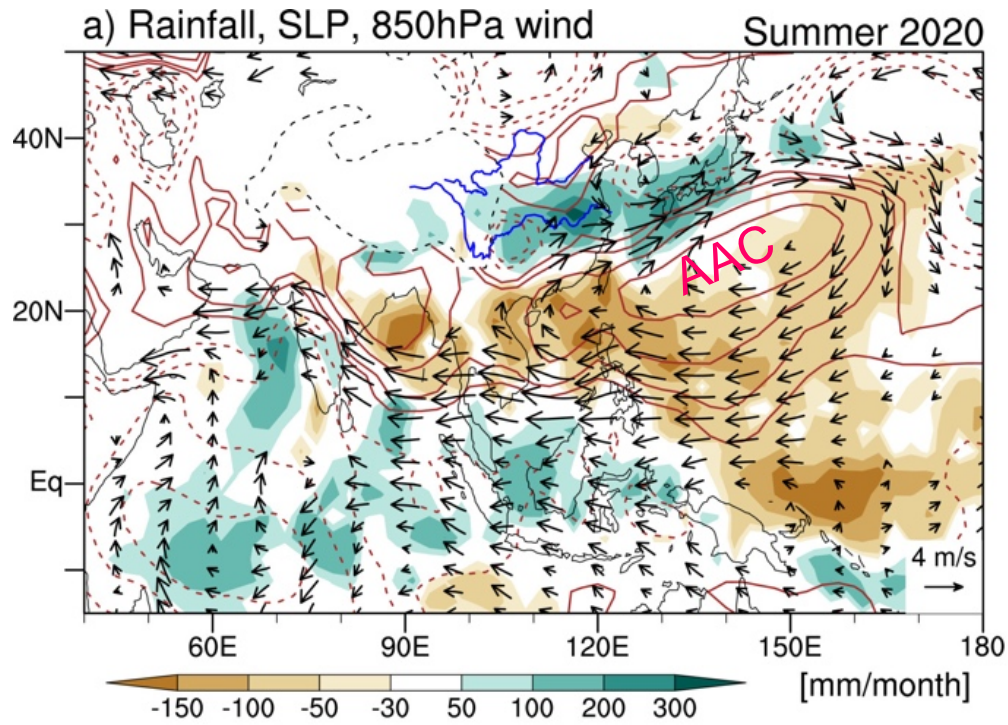
# Anomalous anticyclone (AAC) & Great Yangtze flooding of 2020



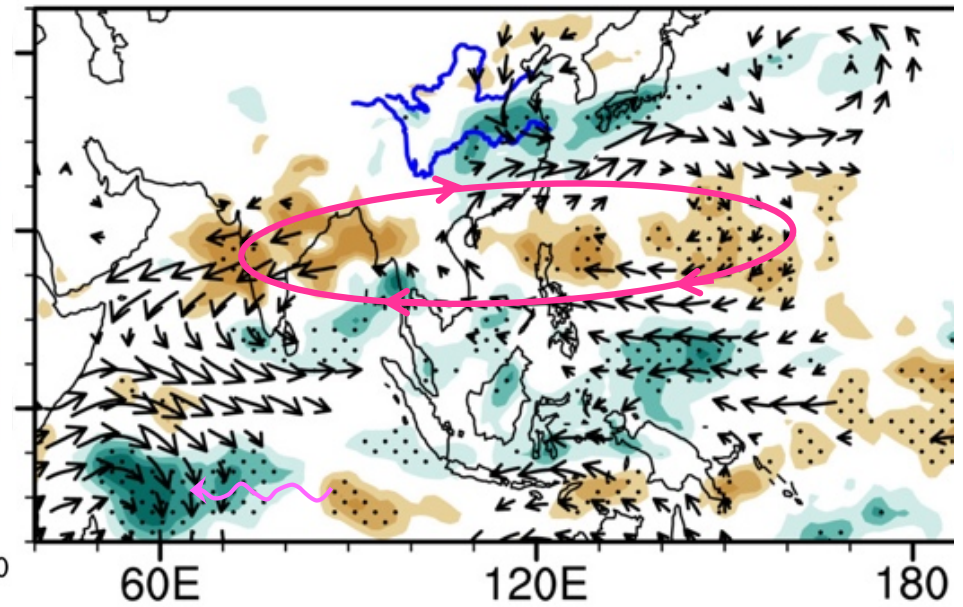
Wuhan, 8 July 2020



**Observed:** Excessive Meiyu rainfall, AAC & IO warming

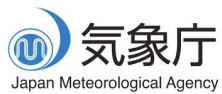
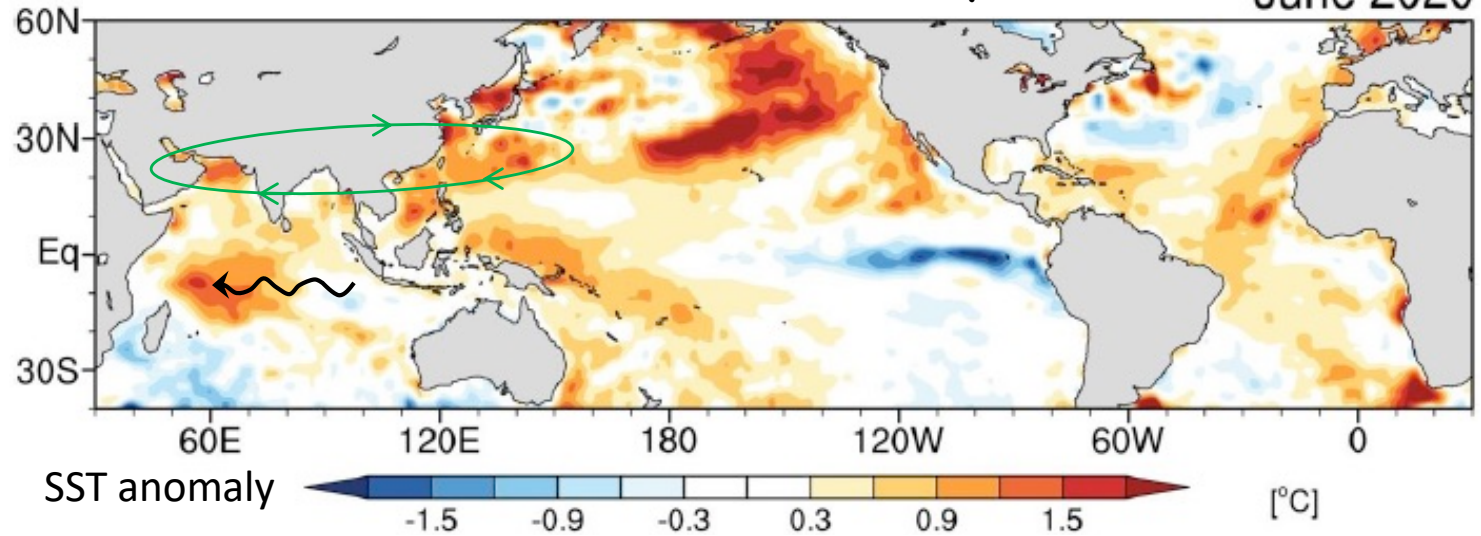


Atmospheric model w/ global SST forcing



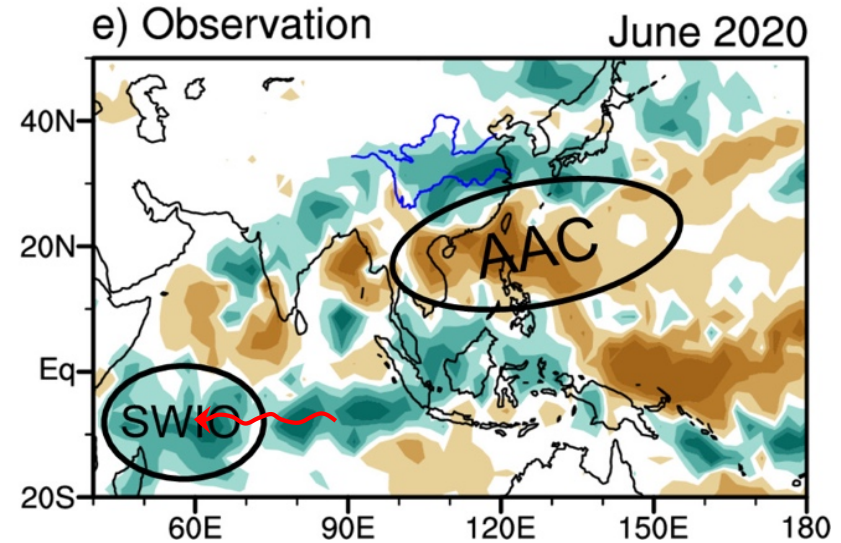
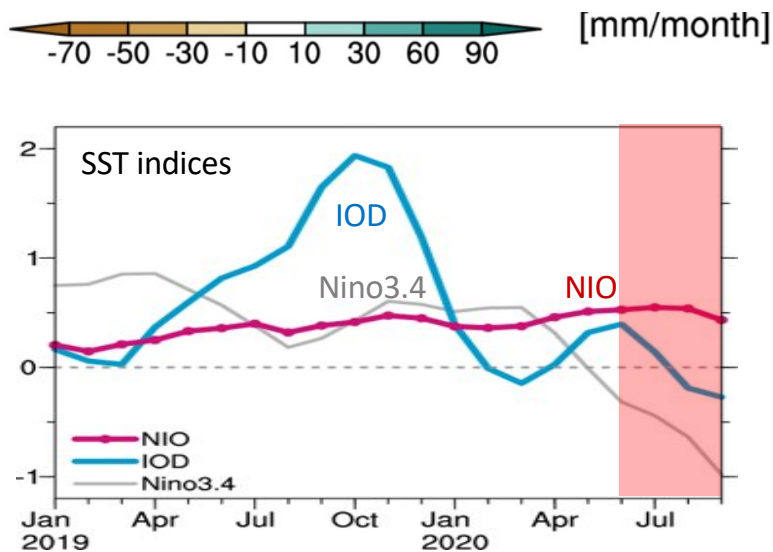
**IPOC** (Indo-western Pacific ocean capacitor)

June 2020



~~El Nino~~ → AAC → heavy Meiyu/Baiu rainfall.

Official/empirical forecasts did not predict the flooding.



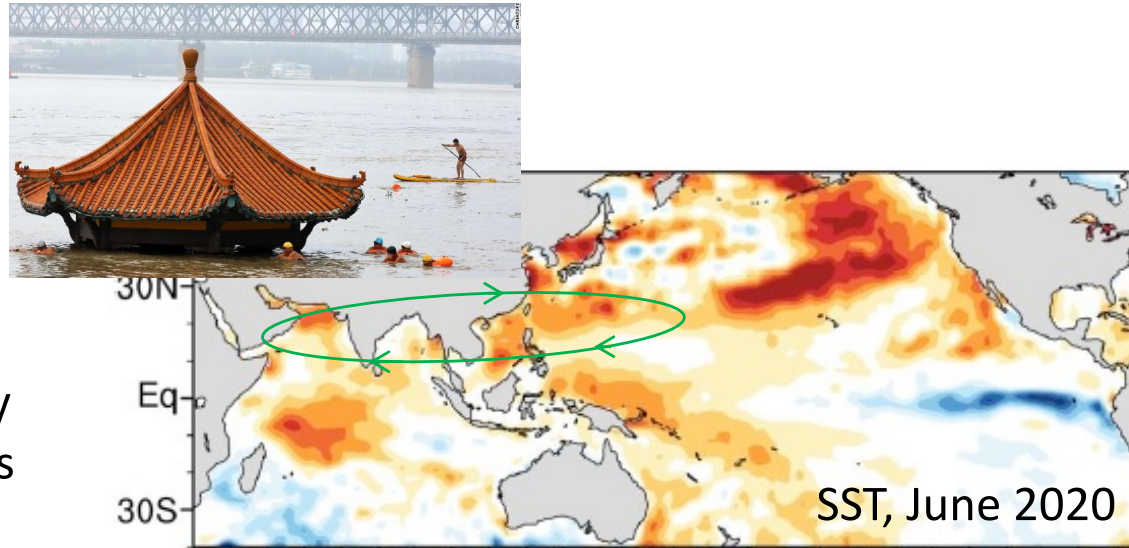
Without major El Nino, 2019-2020 showed an Indian Ocean that is more dynamic and more predictable than thought.

Zhou et al. (2021, PNAS)

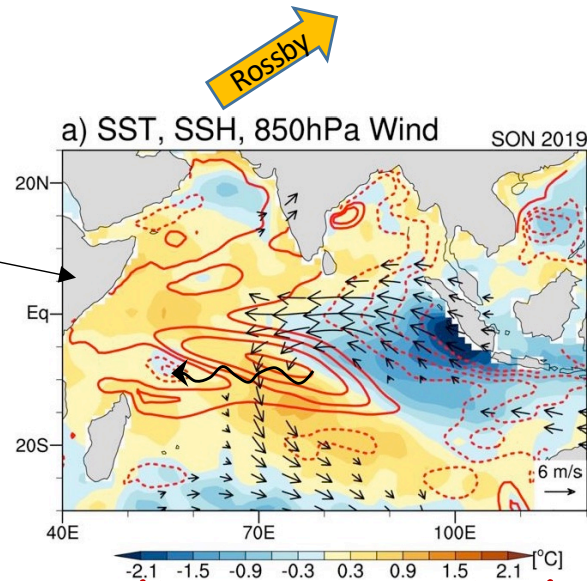


Zhou, Z.-Q., S.-P. Xie, and R. Zhang, 2021: Historic Yangtze flooding of 2020 tied to extreme Indian Ocean conditions. *PNAS*, 118, e2022255118.

IOD and IPOC are often forced by El Nino but not during 12 months of Sept 19 - Aug 20.



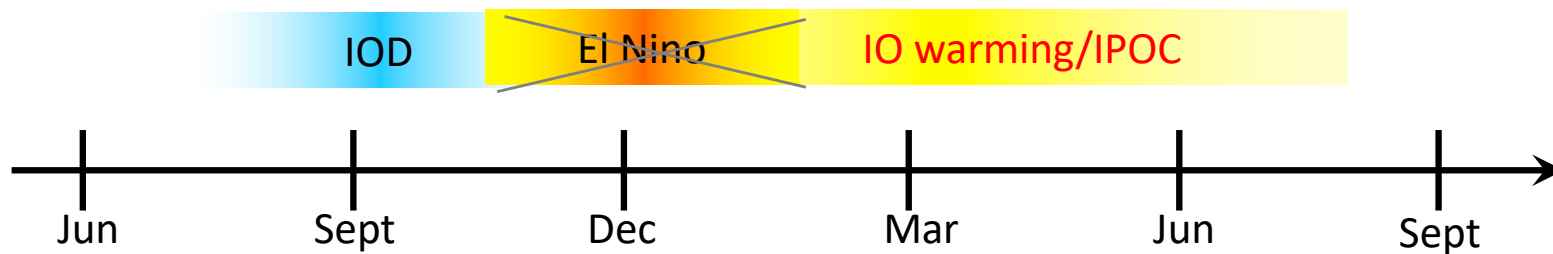
**Indian Ocean warming** → AAC → excessive rains  
June-August 2020



**Indian Ocean Dipole**  
Sept-Nov 2019



- IPOC affects summer rainfall over India and eastern China.
- IOD and IPOC are coupled modes, which are often, but **not always, forced by El Nino**.
- Indian Ocean is **more predictable** than recognized.



### Outstanding issues

- IOD prediction: ENSO & stochastic (MJO) forcing
- IPOC predictors: ENSO, IOD, and ???
- IPOC monitoring indices: TIO SST (**JMA**), AAC or ???
- AAC as a mode of monsoon variability