Changing ENSO properties and Asian Monsoon climate prediction

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The changing properties of ENSO can fundamentally affect monsoon climate forecasting.

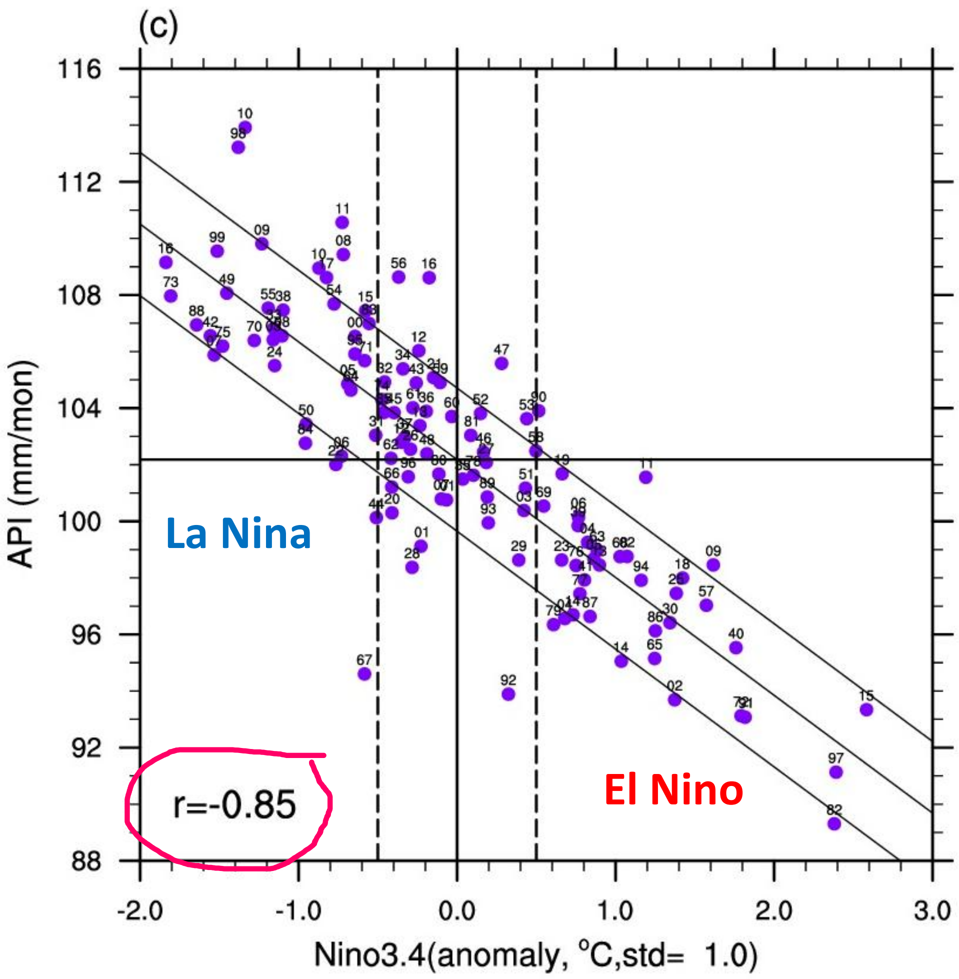
This talk discusses

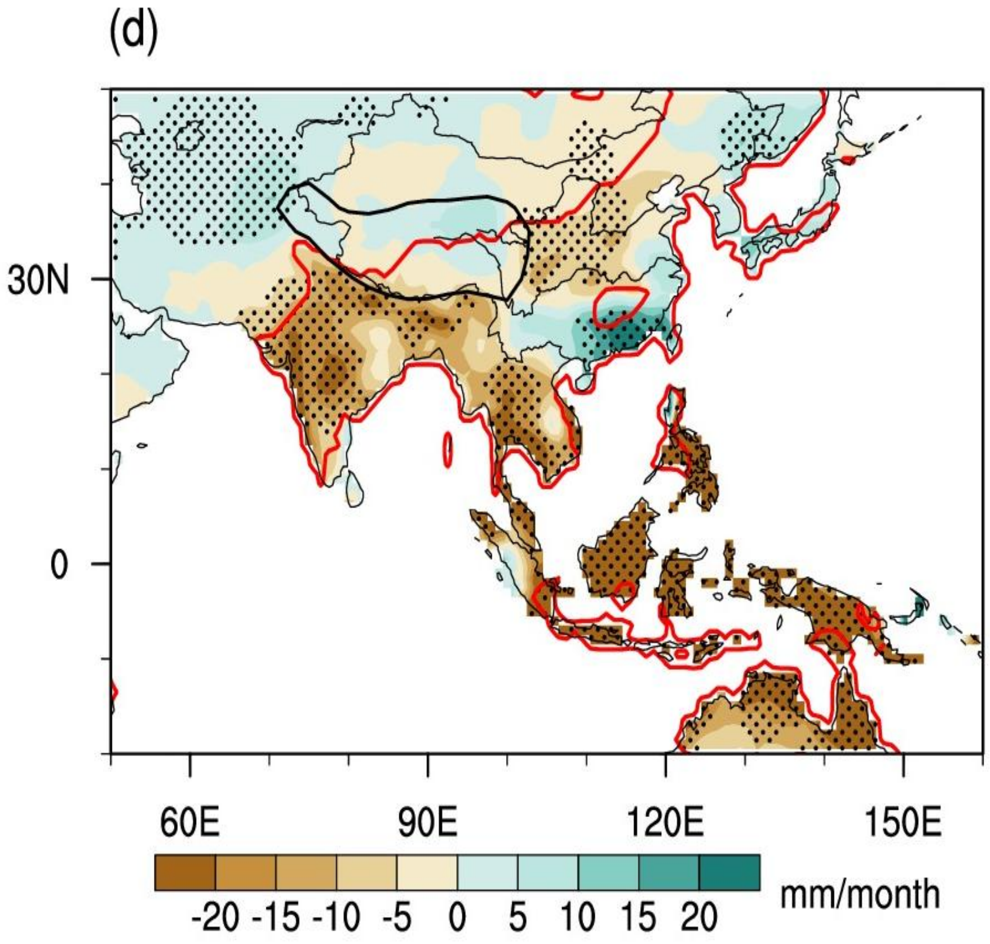
- The Asian Precipitation (AP)- ENSO relationship and its historical change over the past 120 years.
- Three types of El Niño events have distinct impacts on Asian monsoon rainfall.
- Historical changes in the characteristics of El Niño and La Niña over the last century and their causes.

I. AP (Asian Precipitation)-ENSO relationship

Wang, B. X. Luo, and J. Liu, 2020: How Robust is the Asian Precipitation–ENSO Relationship during the Industrial Warming Period (1901-2017)? *J. Climate*, 33, 2779-2792.

Monsoon year (May(0)-April(1)) Asian Precipitation



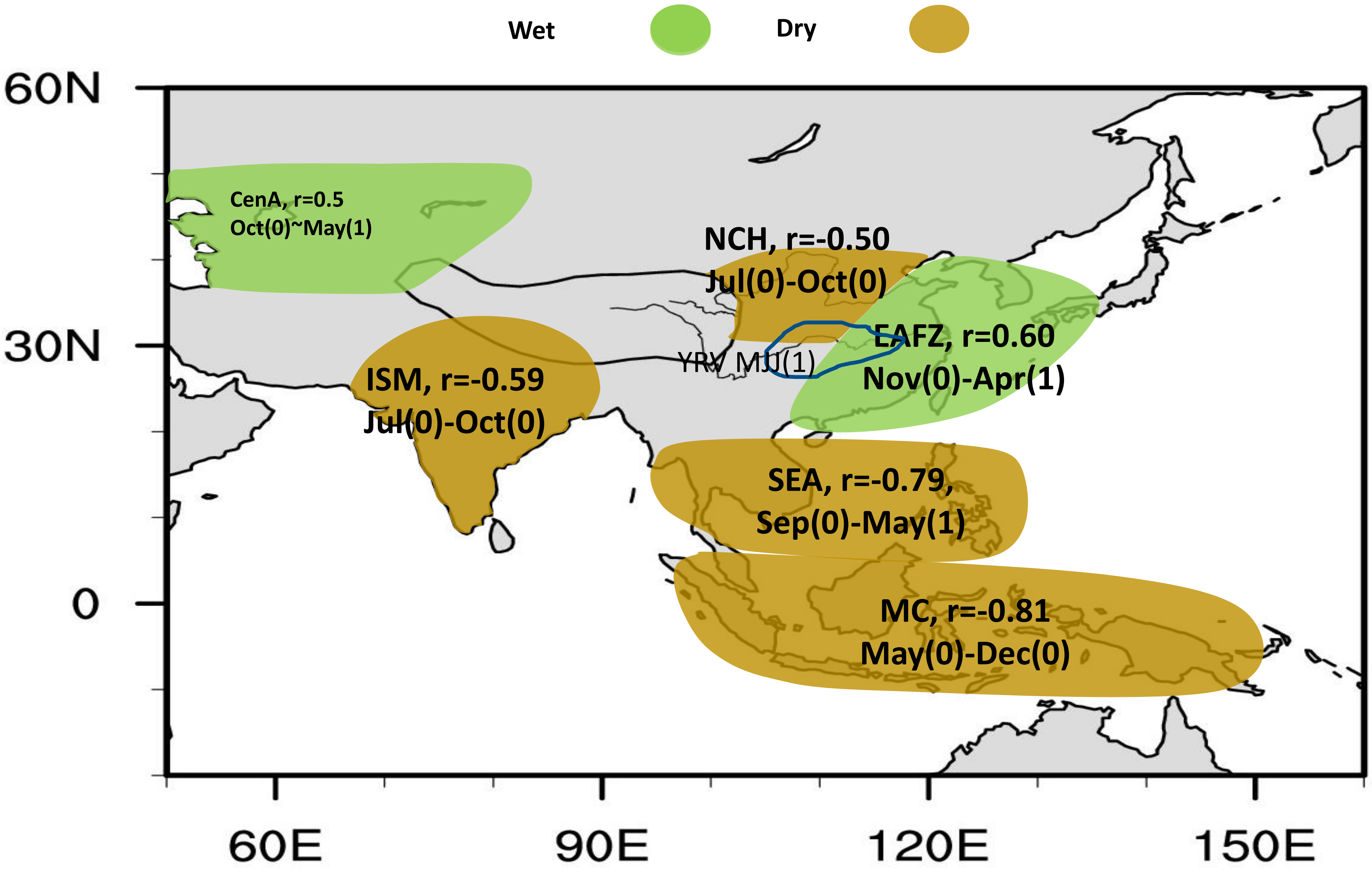


API: Averaged Asian monsoon precipitation rate over land (mm/Month)

Asian precipitation index (API) decreases (increases) during El Nino (La Nina) years.

API decreases by 4.5% for 1K of SST increase in the ECP (Nino 3.4 region).

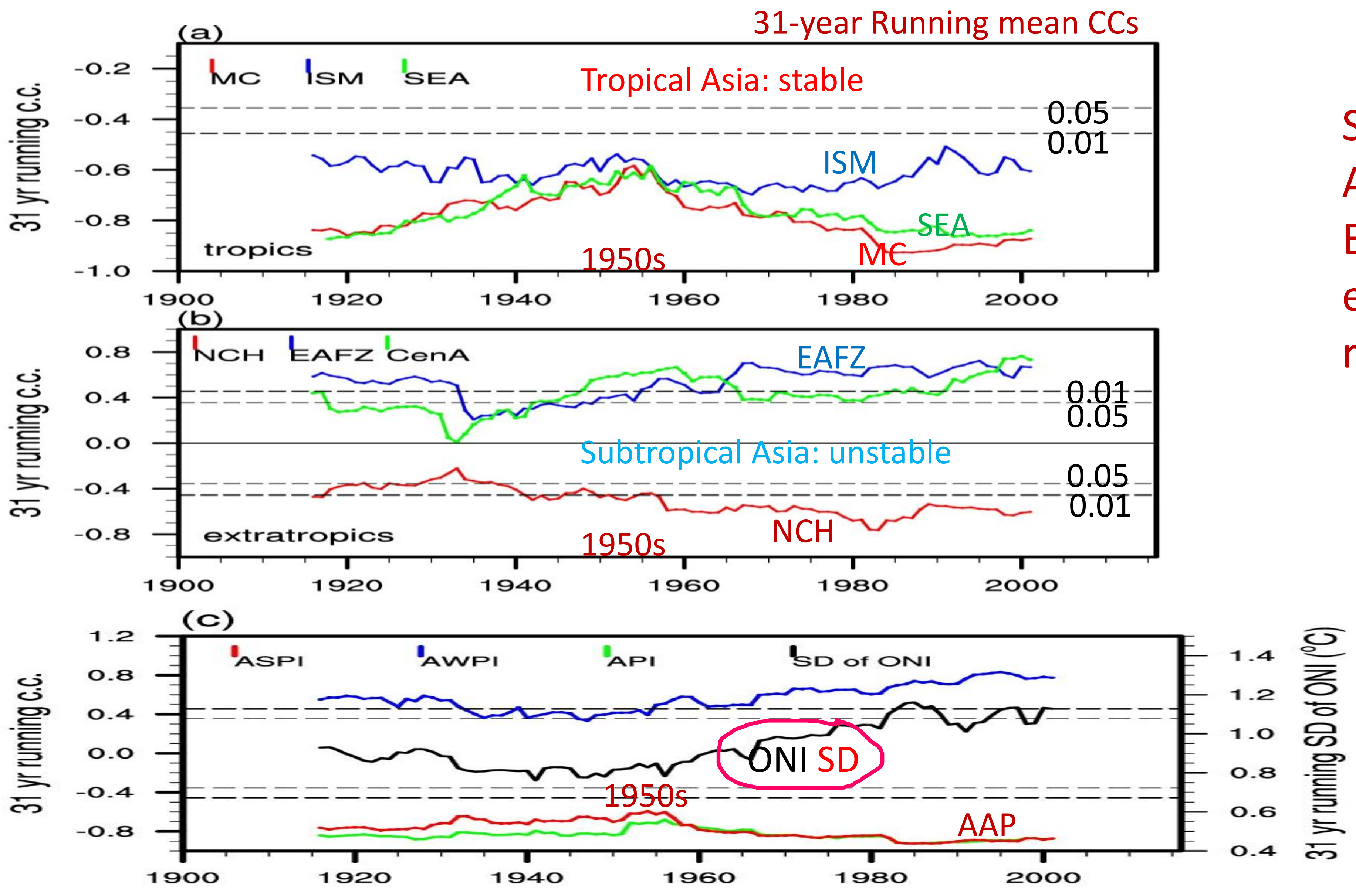
Regional and seasonal dependence of the AP response to ENSO



Six sub-regions significantly correlate with ONDJF ONI (1901-2017), with absolute values of CCs exceeding 0.5 ($p<0.001$).

Wang et al. (2020)

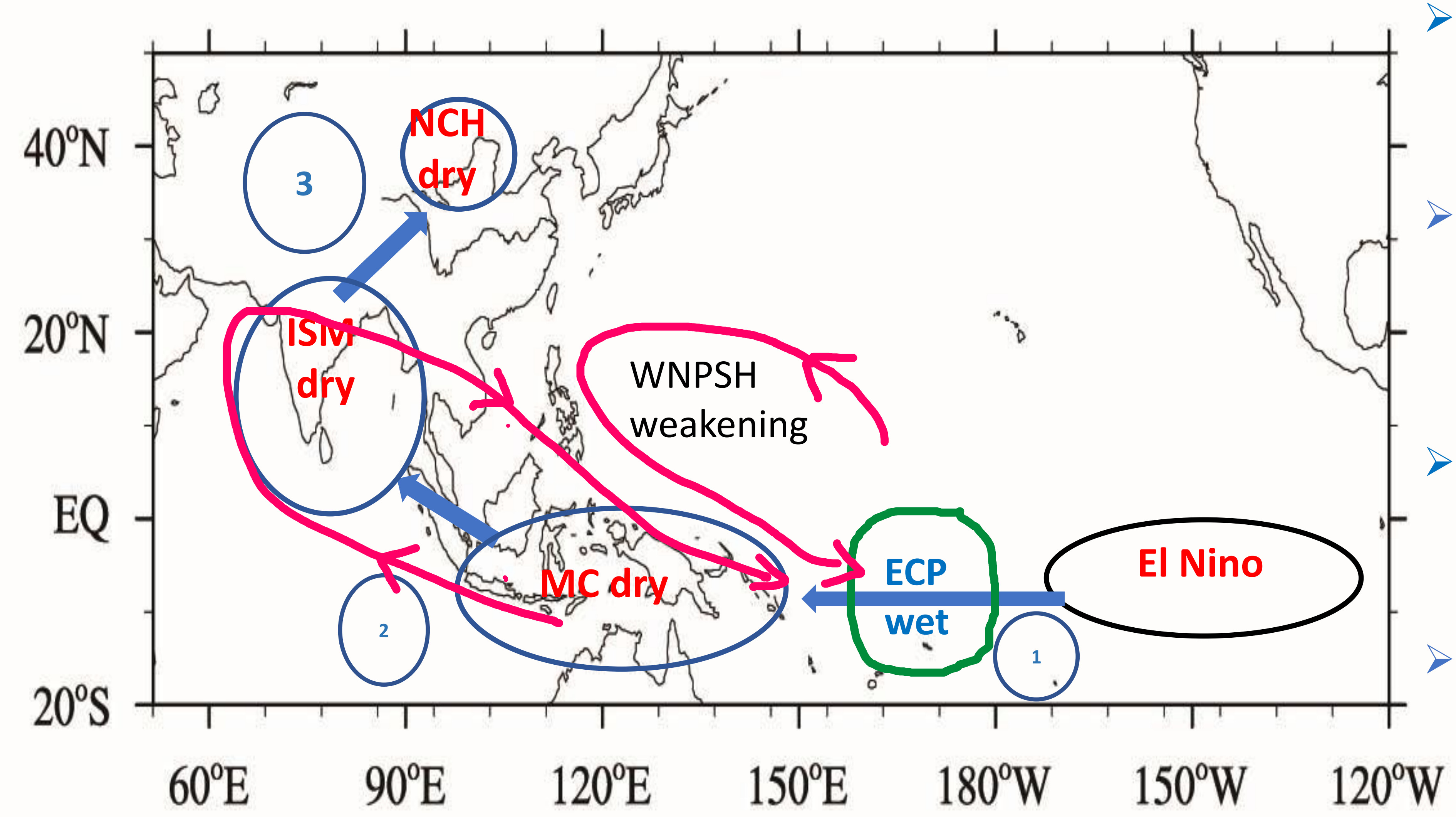
Historical changes in AP-ENSO relationship (1901-2017)



Since the 1950s, the AP relationships with ENSO have been enhanced in all sub-regions except India.

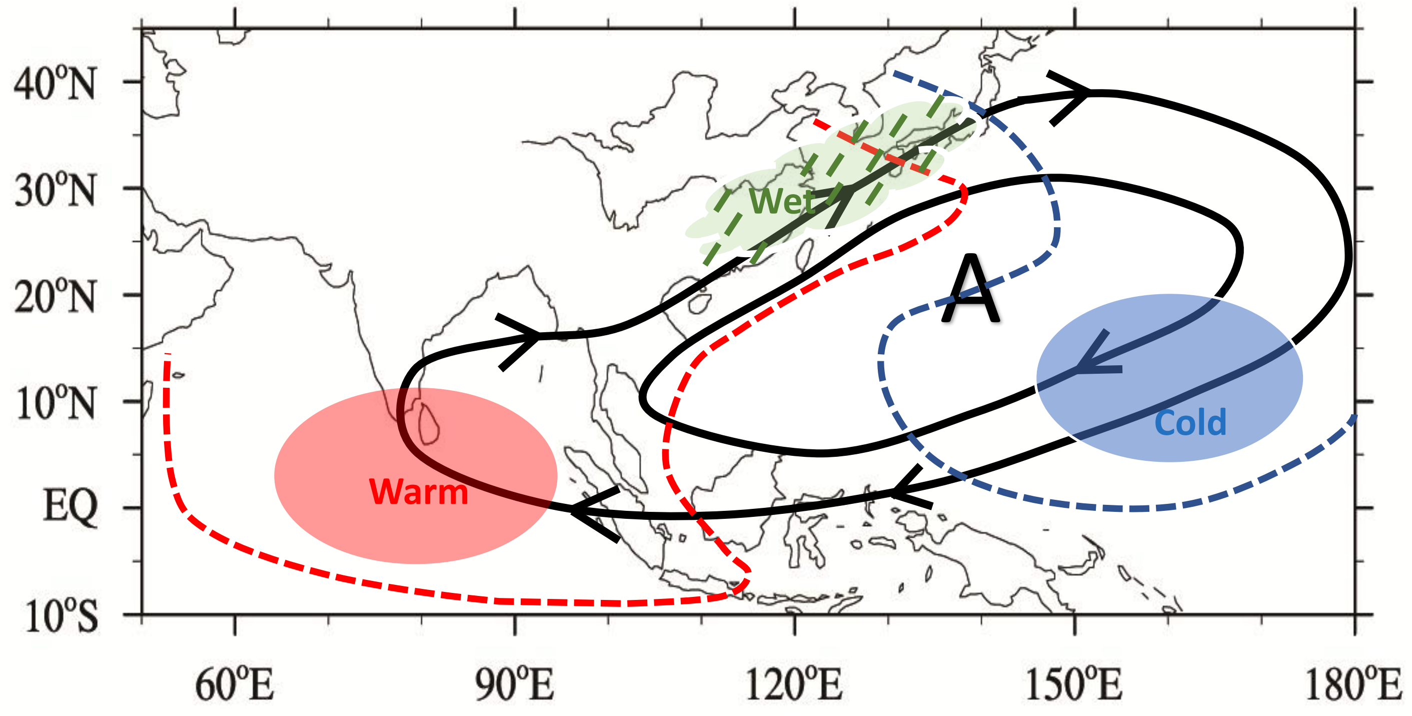
Controlling factor: ENSO amplitude

Physical Processes by which ENSO affect ASM
during an El Niño developing Summer JASO (0)



- El Nino suppresses MC and enhances ECP convection by efficient Kelvin wave propag.
- Suppressed MC precipitation excites Rossby Waves under monsoon easterly vertical shear, drying ISM.
- The reduced ISM heating decreases northern China's rainfall by exciting the Rossby wave train.
- Enhanced ECP heating weakens WNPSH by exciting Rossby wave lows, weakening EASM.

Physical mechanism explaining how El Niño affects EASM during Post-El Niño spring and summer (FMAMJJ(1))



Wang et al. (2020)

Interaction between WP AAC and Indo-Pacific SST dipole

Wang et al. (2013): WP AAC and Indo-Pacific SST dipole coupled mode.

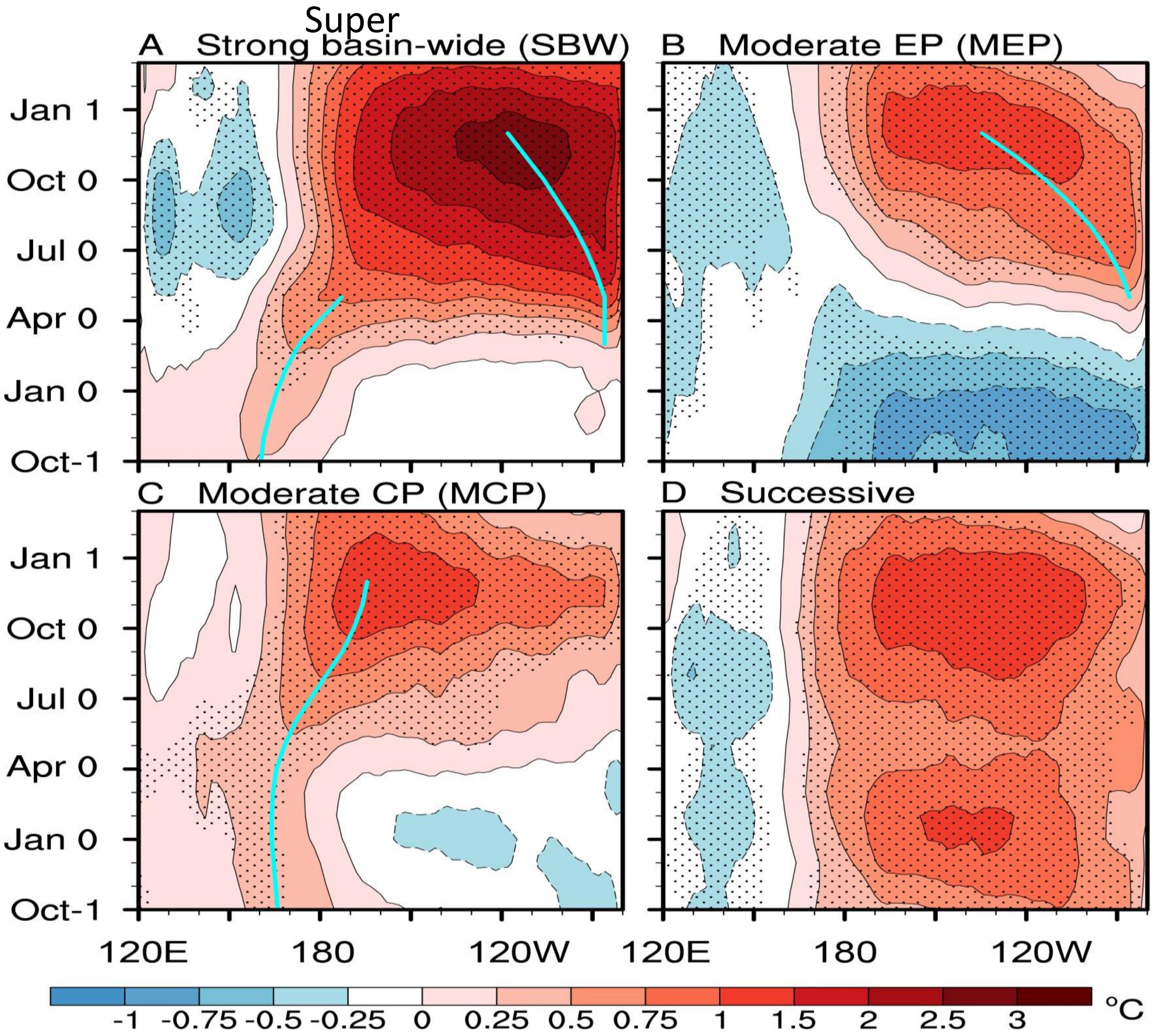
Xie et al. (2016): Indo-Pacific capacitor

II. Three types of El Niño and their impacts on Asian monsoon rainfall

The current classification of El Niño (EP and CP) is based on boreal winter mature phase SST patterns. However, ASM is during its development and decay phases in boreal summer. A new classification based on El Niño evolution was advanced.

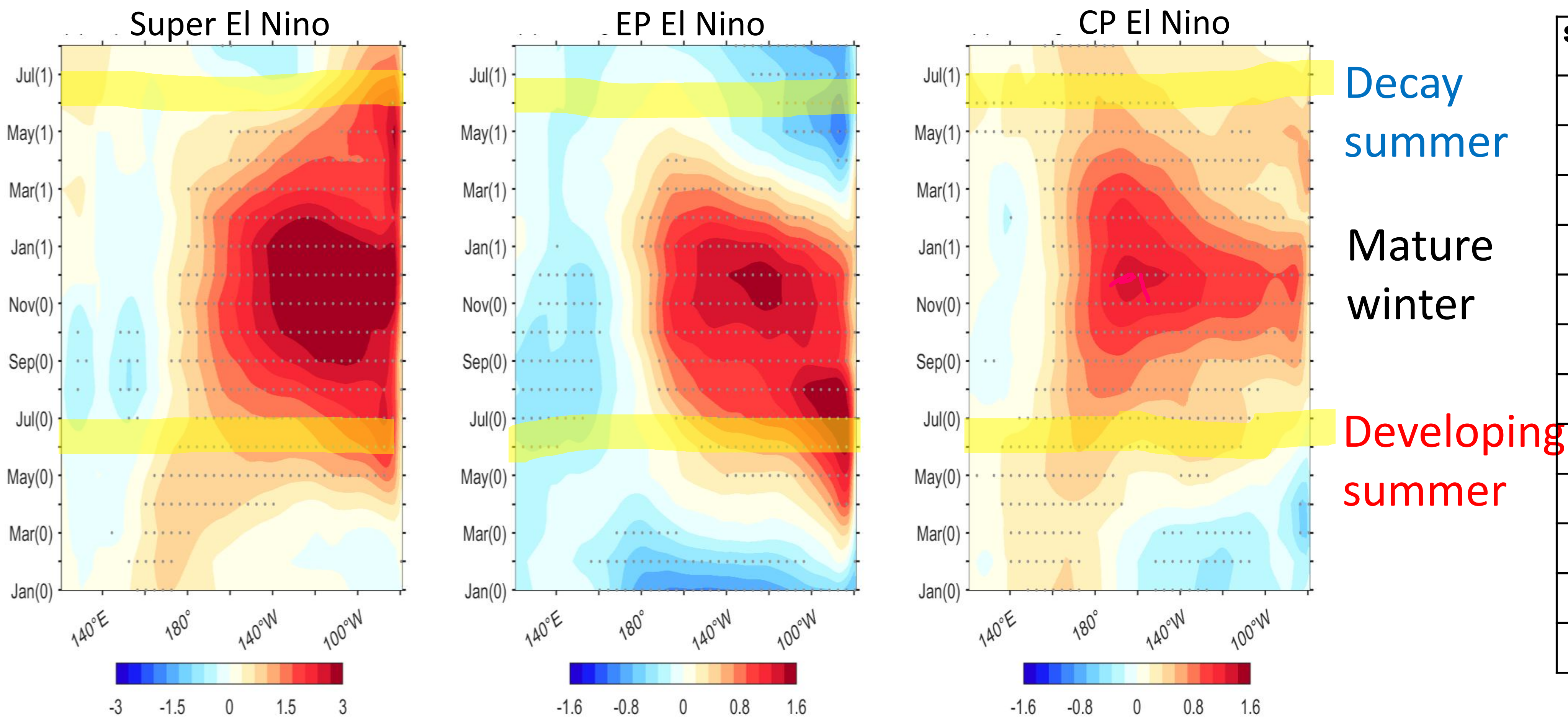
Wang, B., X. Luo, Y.-M. Yang, W. Sun, M. A. Cane, W. Cai, S.-W. Yeh and J. Liu, 2019: Historical change of El Niño properties sheds light on future changes of extreme El Niño. PNAS, 116(45), 22512-22517.

A new look at El Niño diversity: Super, EP, CP, and Consecutive



K- mean cluster analysis of the onset and evolution processes of 33 El Niño events reveals Super (Strong basin-wide), Moderate Eastern Pacific (EP), Central Pacific (CP) events. Each exhibits distinct development mechanisms. Super and CP events share a common initiation from the WP.

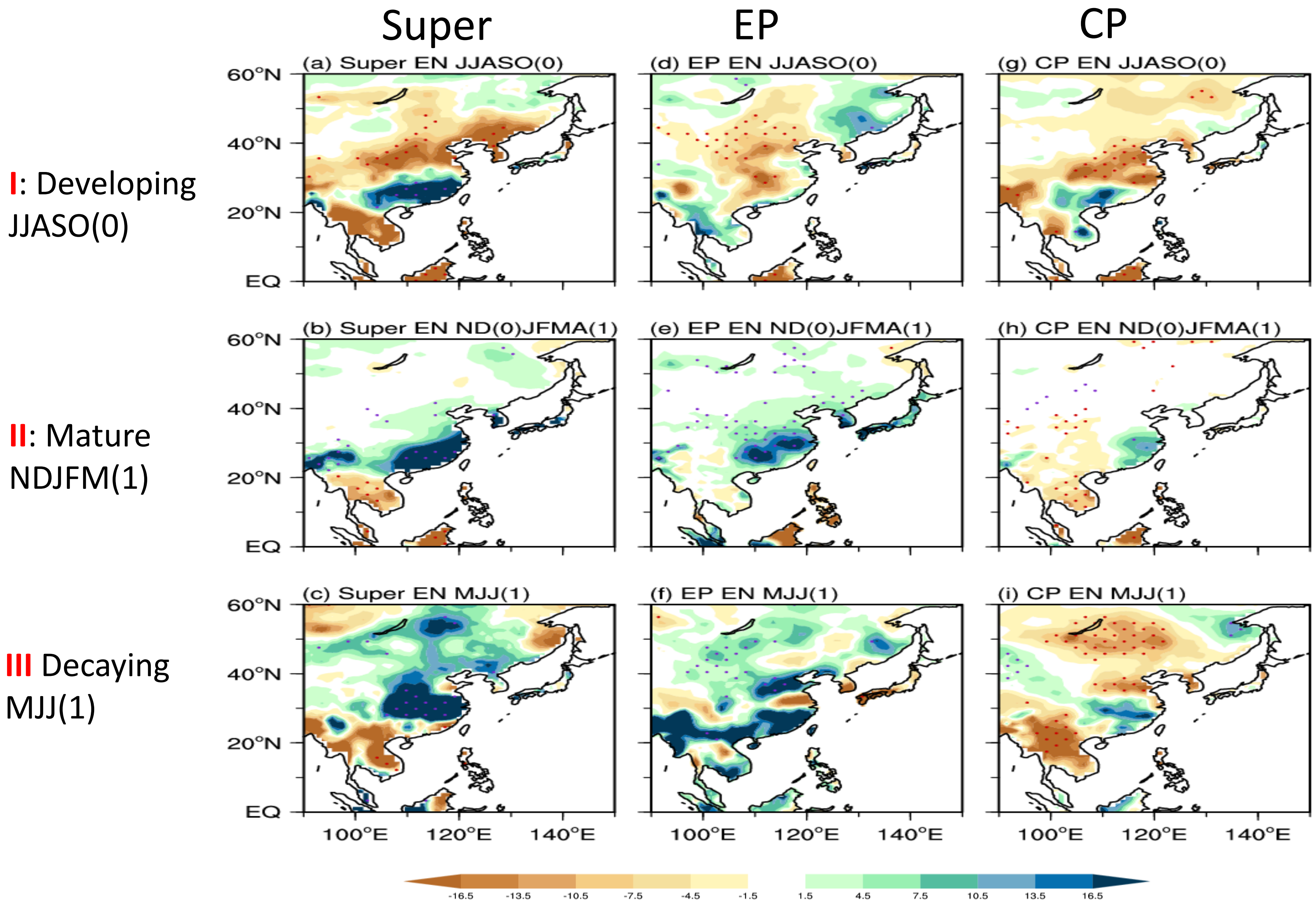
Distinct Evolutions of the Equatorial SSTA



Super El	EP El	CP El	
1982	1951	1968	
1997	1957	1986	
2015	1963	1991	
	1965	1994	
	1972	2002	
	1976	2004	
	2023	2006	
		2009	
		2014	
		2018	

Remarkable different equatorial Pacific SST anomaly Patterns during Developing and decaying Phases

El Nino Diversity-dependent rainfall response

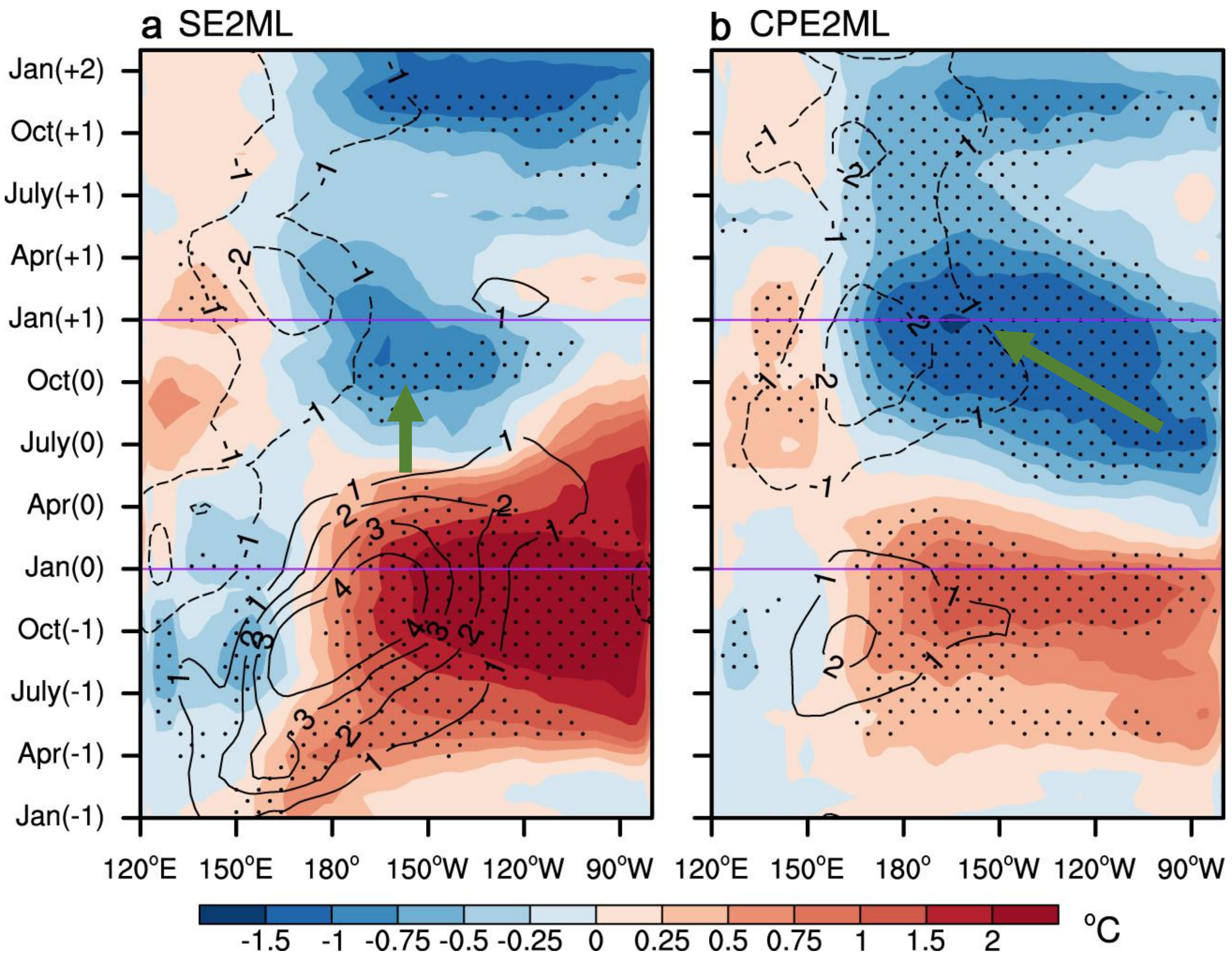


- Super El has the most significant impacts
- CP El has a stronger influence than EP during the developing summer
- EP has a stronger influence than CP during the mature and decaying phases.

Two types of Multiyear La Niña following Super or CP El Nino

Three Super El Niño-to-ML (SE2ML): 1983–84, 1998–2000, 2016–2017

- Cooling starts from CP
- Onset: June-September (0)
- A weak, standing first-year La Niña
- An enhanced second-year LN



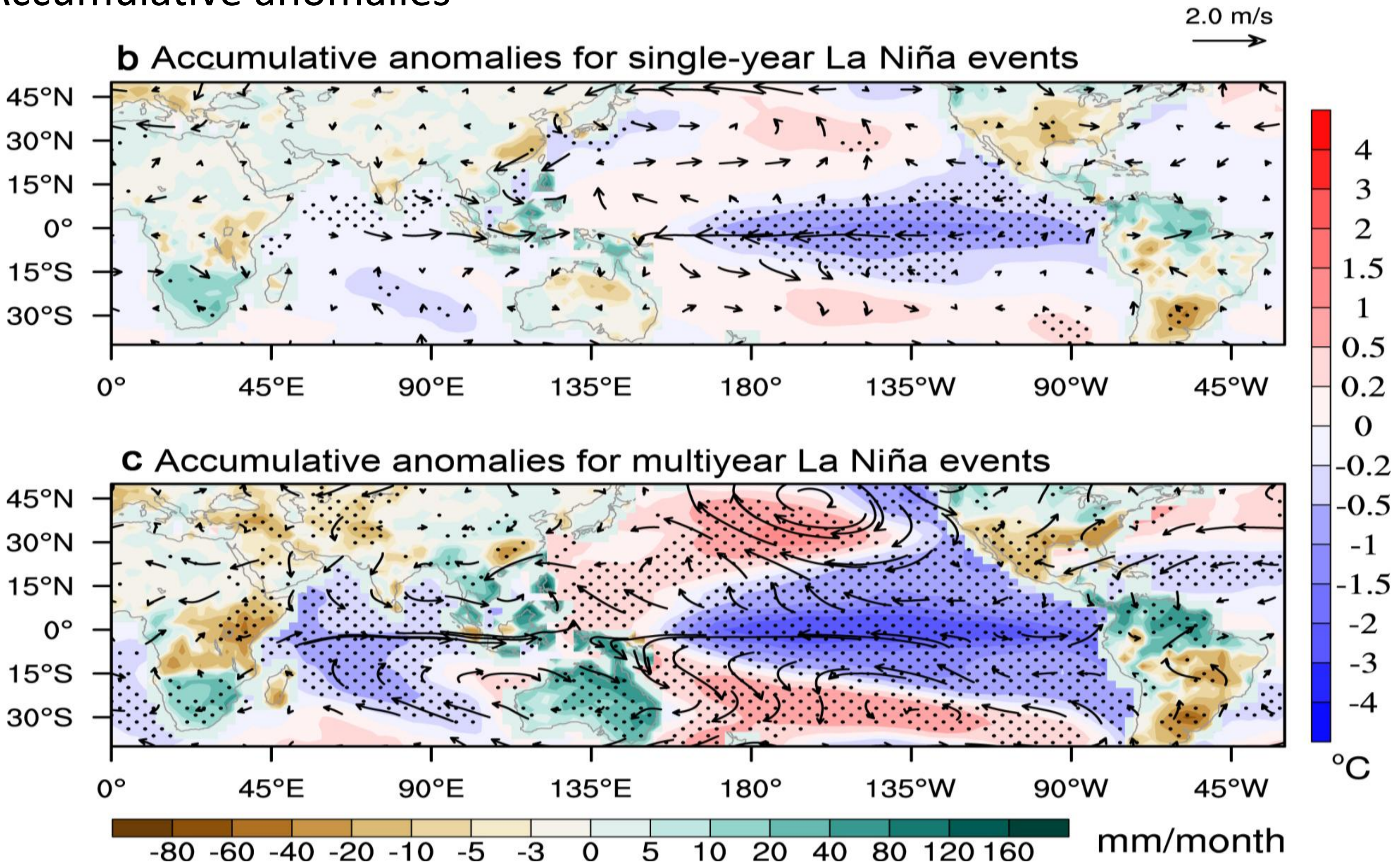
Five central Pacific El Niño-to-ML (CPE2ML): 1970–71, 1973–75, 2007–08, 2010–11, 2020–2022

- Cooling starts from EP
- Onset: March-June (0)
- A strong, westward propagating first-year La Niña
- A decaying second-year La Niña

Two types of multiyear La Niña events follow super or CP El Nino events.

Multiyear La Niña has more Enduring impacts

Accumulative anomalies

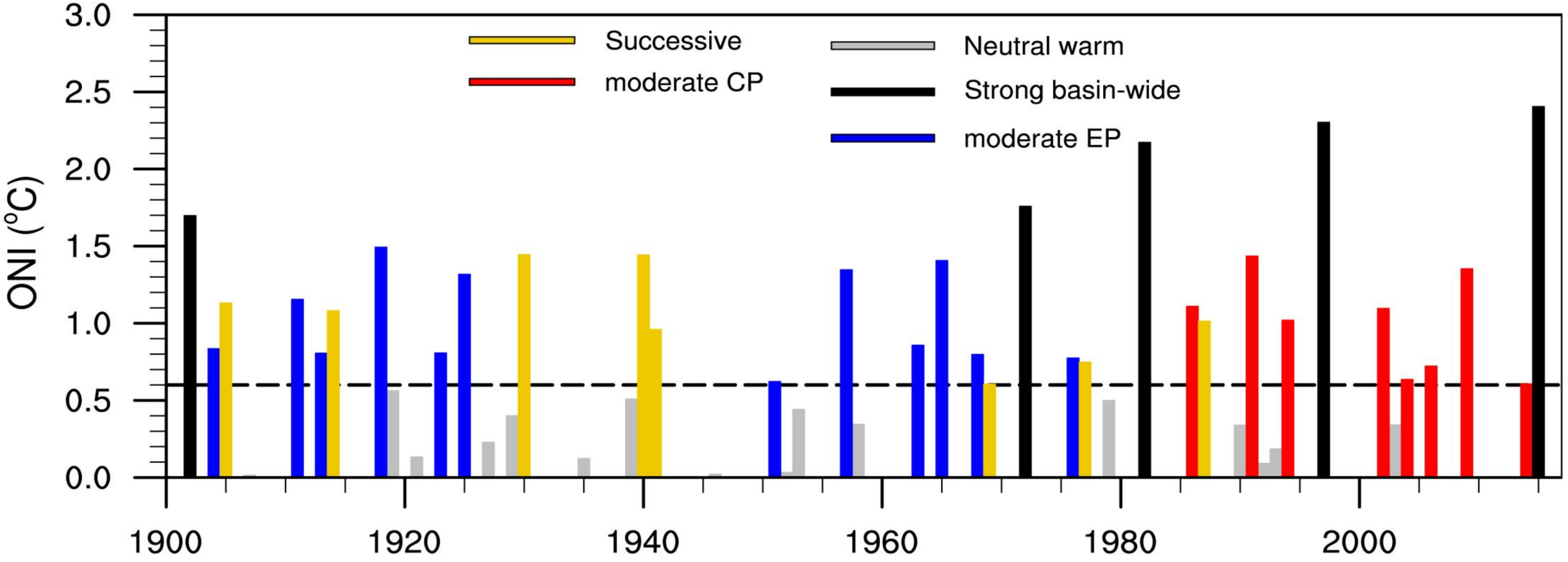


ML has remarkably more enduring impacts than single-year La Niña because their persistence creates substantially vaster SST anomalies in the Pacific and the Indian Ocean

III. Historical changes in ENSO properties and their Causes: Implication to future changes

Wang, Bin, W. Sun, C. Jin, X. Luo, Y.-M. Yang, T. Li, B. Xiang, M. J. McPhaden, M. A. Cane, F. Jin, F. Liu & J. Liu, 2023: Understanding the recent increase in multiyear La Niñas. *Nature Climate Change,* https://doi.org/10.1038/s41558-023-01801-6.

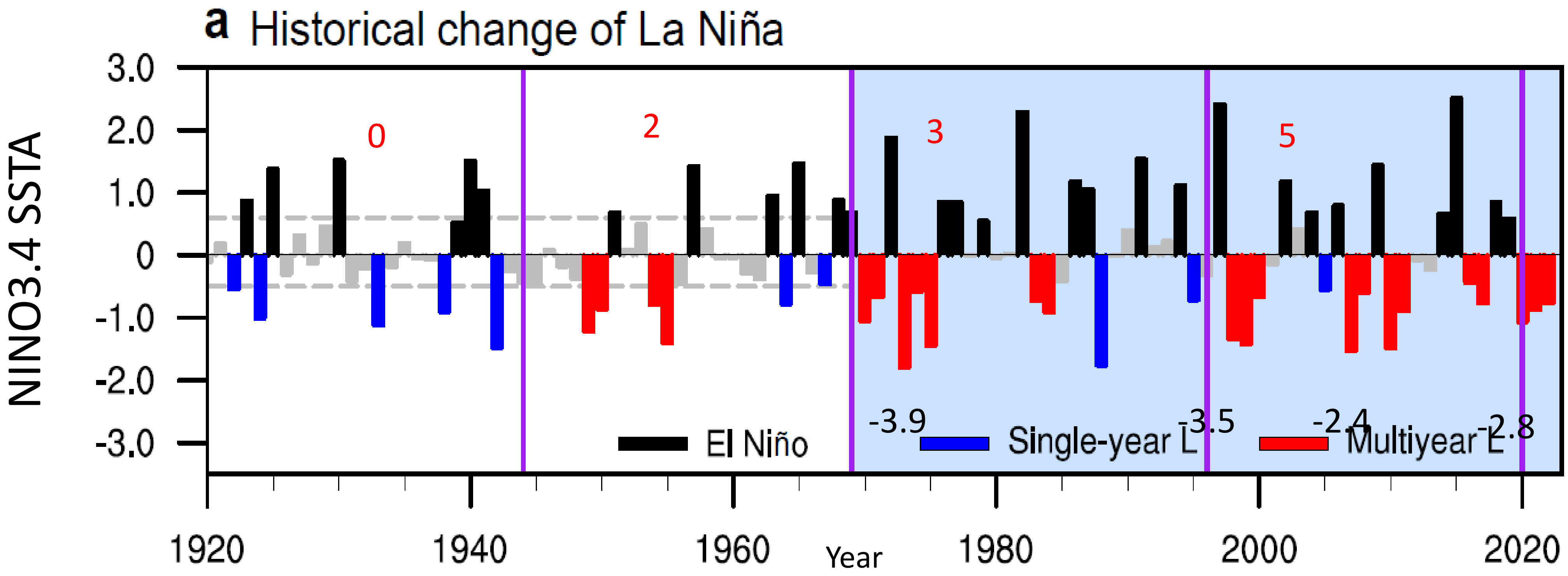
Changes in El Nino diversity since 1901



Since the 1970s, EP El Niño events almost disappeared, replaced by CP and Super El Nino. Both CP and Super El Nino initiated from the western Pacific.

Wang et al. 2019: Historical change of El Niño properties sheds light on future changes of extreme El Niño. PNAS, 116(45), 22512-22517.

A phenomenal increase in multiyear (extreme) La Niña



La Niña: ONDJF mean NINO3.4 less than -0.5° C. Total of 20 La Niña events: ten single-year and ten multiyear La Niña.

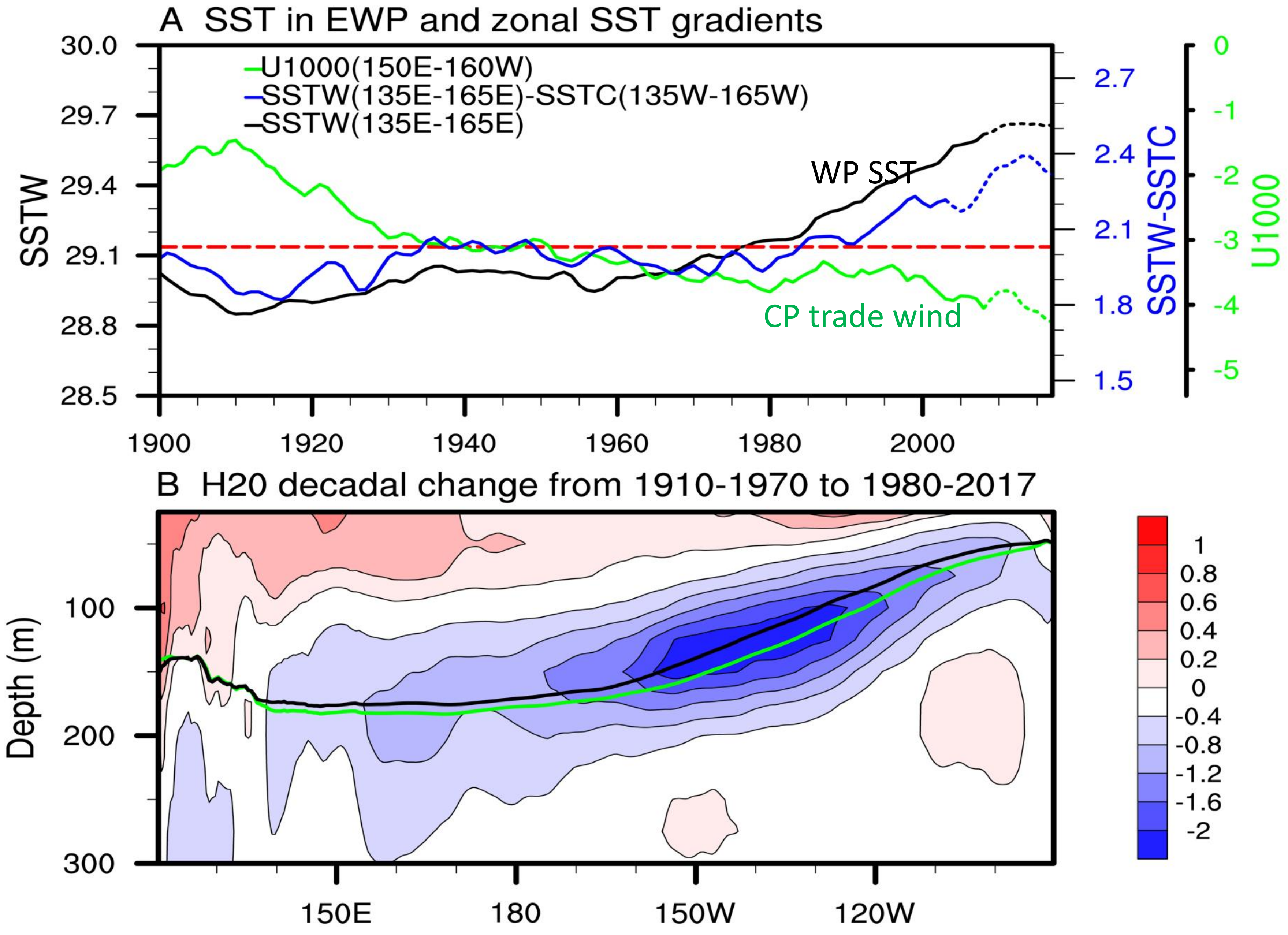
Change in frequency: eight out of ten multiyear La Niña occurred after 1970, and five out of six have been multiyear La Nina since 1998

Change of Intensity: Yearly intensity: -0.94 vs. -0.99

(1920-1969 vs 1970-2022) Accumulative intensity: -1.17 vs. -2.0

Wang, Bin, W. Sun, C. Jin, X. Luo, Y.-M. Yang, T. Li, B. Xiang, M. J. McPhaden, M. A. Cane, F. Jin, F. Liu & J. Liu, 2023: Understanding the recent increase in multiyear La Niñas. *Nature Climate Change,* https://doi.org/10.1038/s41558-023-01801-6.

What has caused the observed change in ENSO properties?

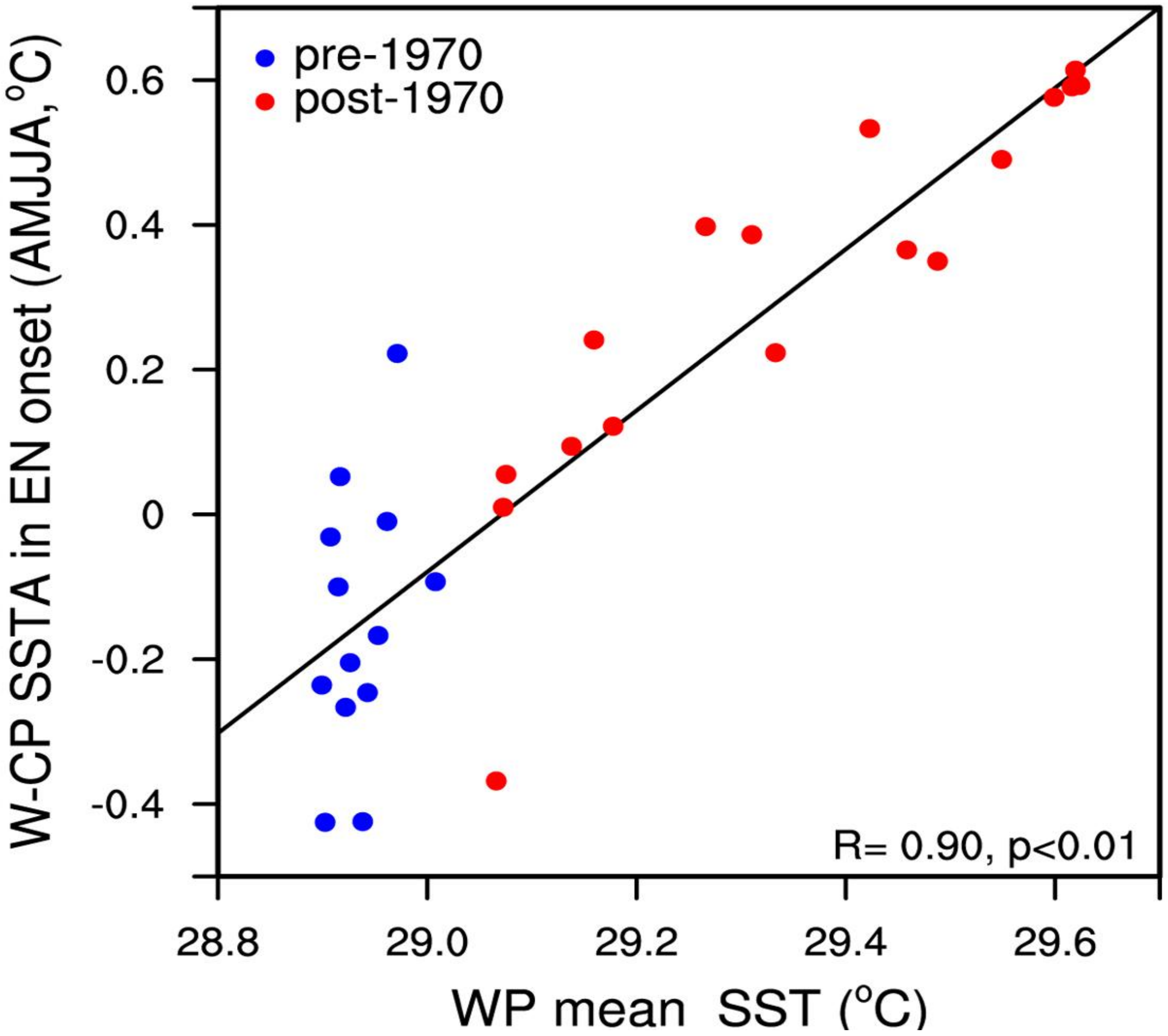


Background state change in the equatorial Pacific.

A. Equatorial SST: EWP (135-165E) SST increases, The zonal SST gradient increased

B. CP thermocline rises. The vertical temperature gradients increase over 150°E–140°W.

WP warming shifts El Niño onset from EP to WP



When EWP becomes warmer than the ECP, the El Niño events tend to onset from the western Pacific due to enhanced zonal advective feedback.

Changes in El Nino and La Nina share same origins

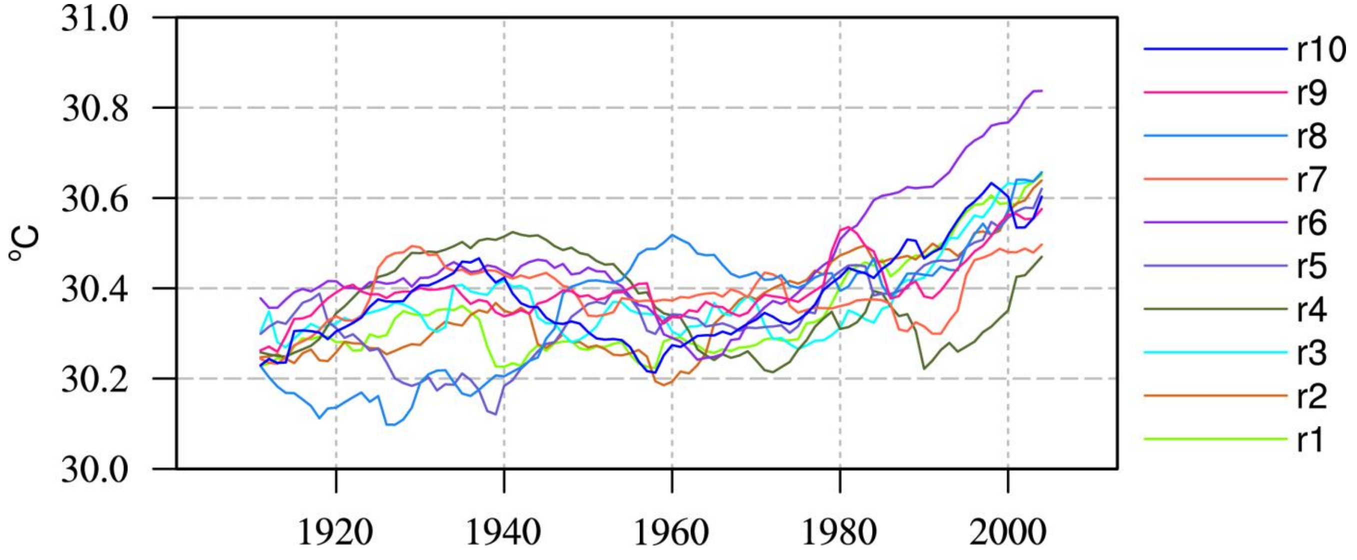
Since the 1970s, El Niño onset has shifted from the eastern Pacific to the western Pacific, leading to more frequent super and CP El Niño events.

Hypothesis: Historical regime change is rooted in background warming in the western Pacific and the associated increases in zonal and vertical temperature gradients in the ECP.

The WP warming enhances zonal advective feedback in the EWP and thermocline feedback in ECP, leading to more frequent Super and Central Pacific (CP) events and increasing the likelihood of multiyear La Niña.

CESM2 large ensemble simulation reproduced the WP warming trend and increased MY La Nina

The simulated western Pacific mean SST in 1981-2010 is 0.24°C higher than the 1901–1930 mean.

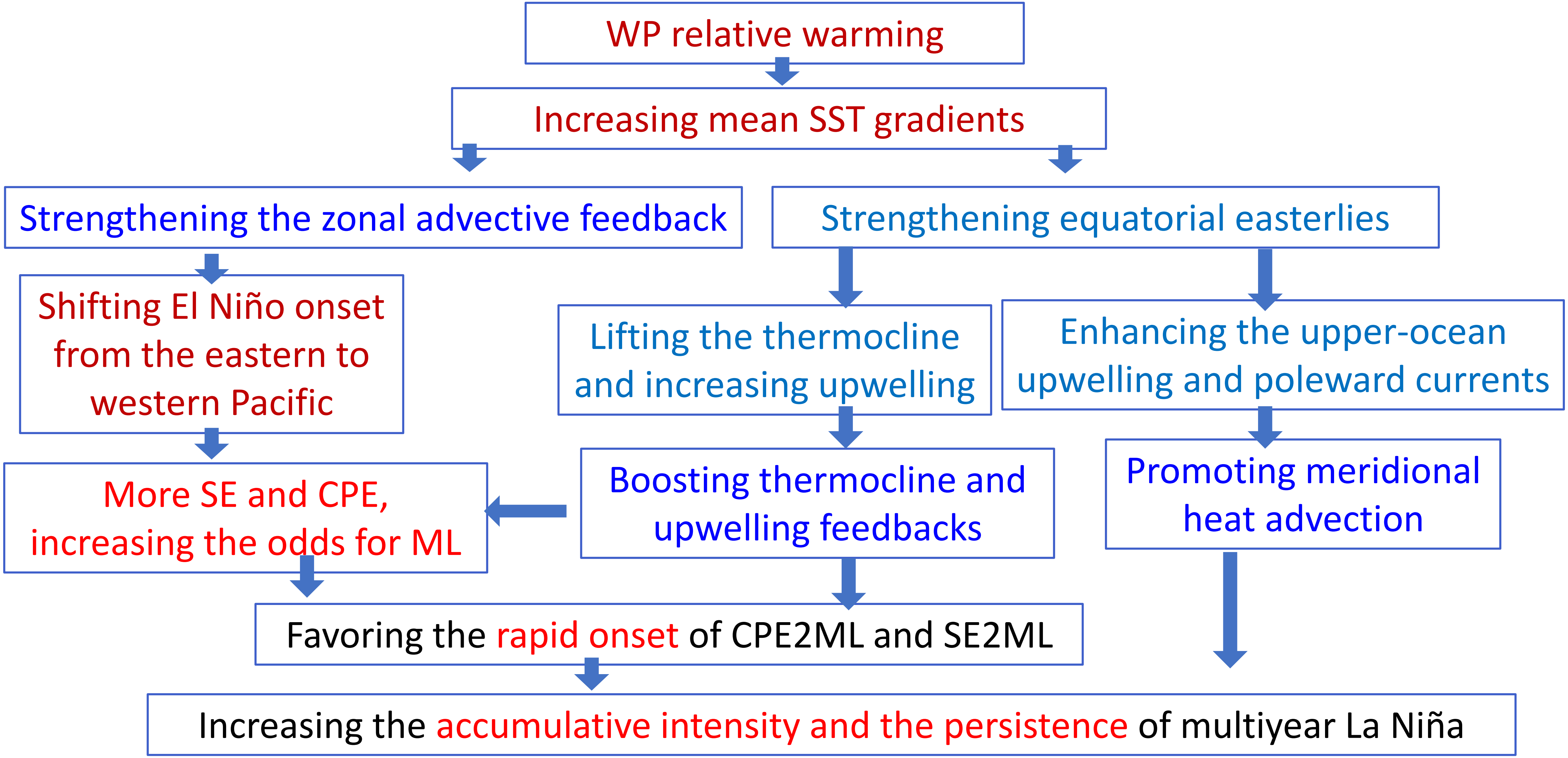


During 1981–2010, the number of multiyear events (91) is nearly three times that of single events (32).

	Single-year La Niña years	Multiyear La Niña years	Total
1901-1930 (30-y)	56	52	108
1981-2012 (30-y)	32	91	123
Total	88	143	231

The degree of freedom is one, and the Chi-Square value equals 15.20 ($p<0.01$)

How does western Pacific warming change El Niño and La Niña?



Implications

If the western Pacific continues to warm relative to the central Pacific,

(1) More extreme ENSO events, such as super El Niño and multiyear La Niña, will exacerbate adverse socioeconomic impacts

(2) The ENSO-AMP relationship will be enhanced, and AM will be more predictable.

Thank you for your comments

Summary

The changing properties of ENSO and their impacts on Asian monsoon rainfall pose a fundamental challenge to climate forecasting.

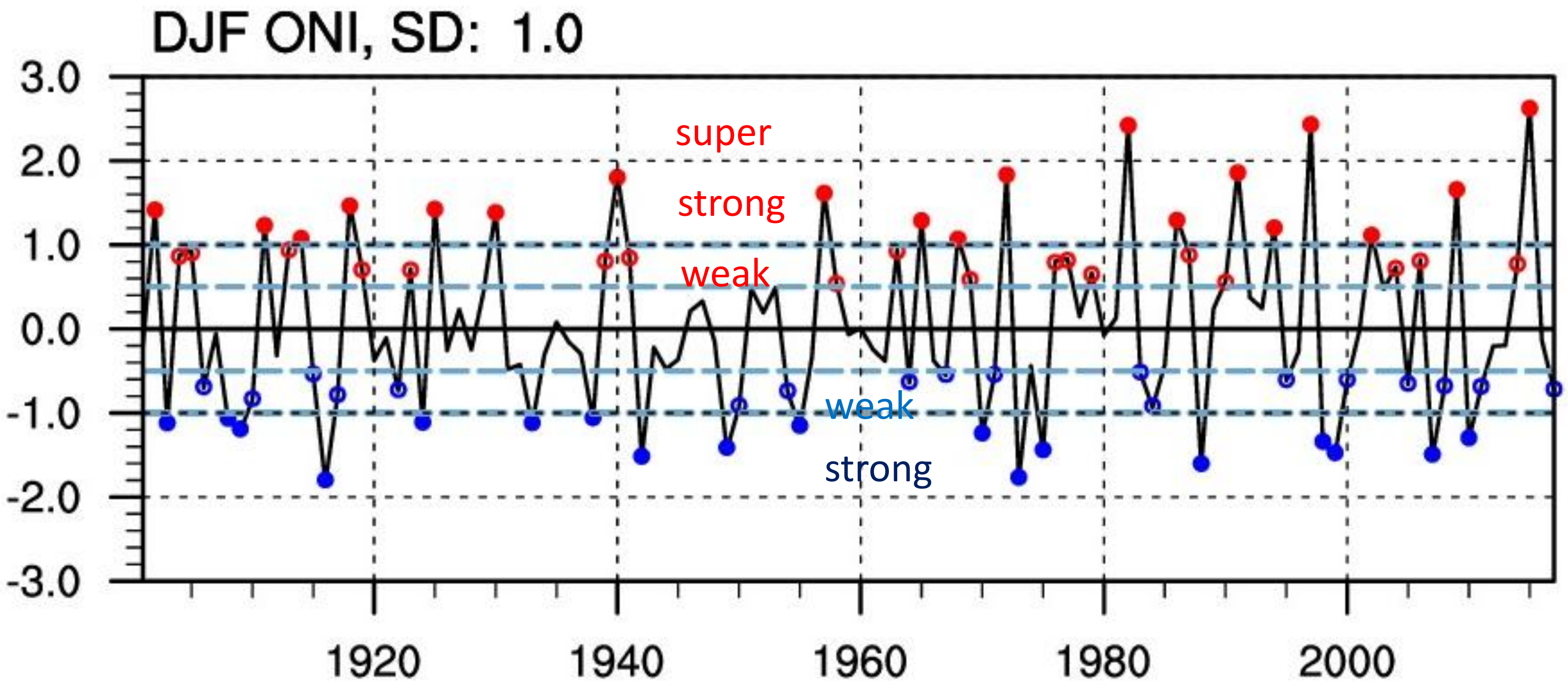
complementary

Data

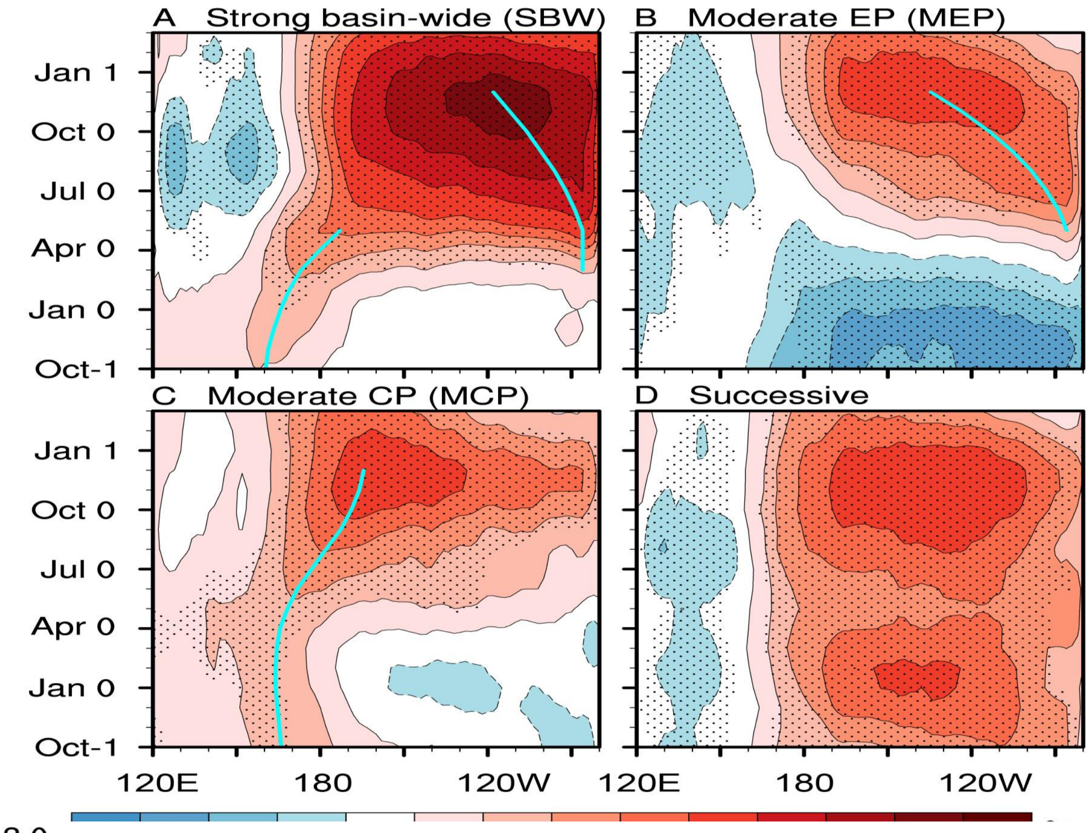
- Precipitation: merged data from (a) Global land Precipitation Climatology Centre (GPCC) dataset (Schneider et al., 2014) and (b) CRU data. 1901-2017
- Circulation: ECMWF merged reanalysis RC 20C+ERA40+ERA interim 1901-2018.
- SST: merged from HadISST (Rayner et al., 2003) and NOAA ERSST V5 (Huang et al., 2015) 1901-2018.
- Student t-test and F-test.

Climate model projection

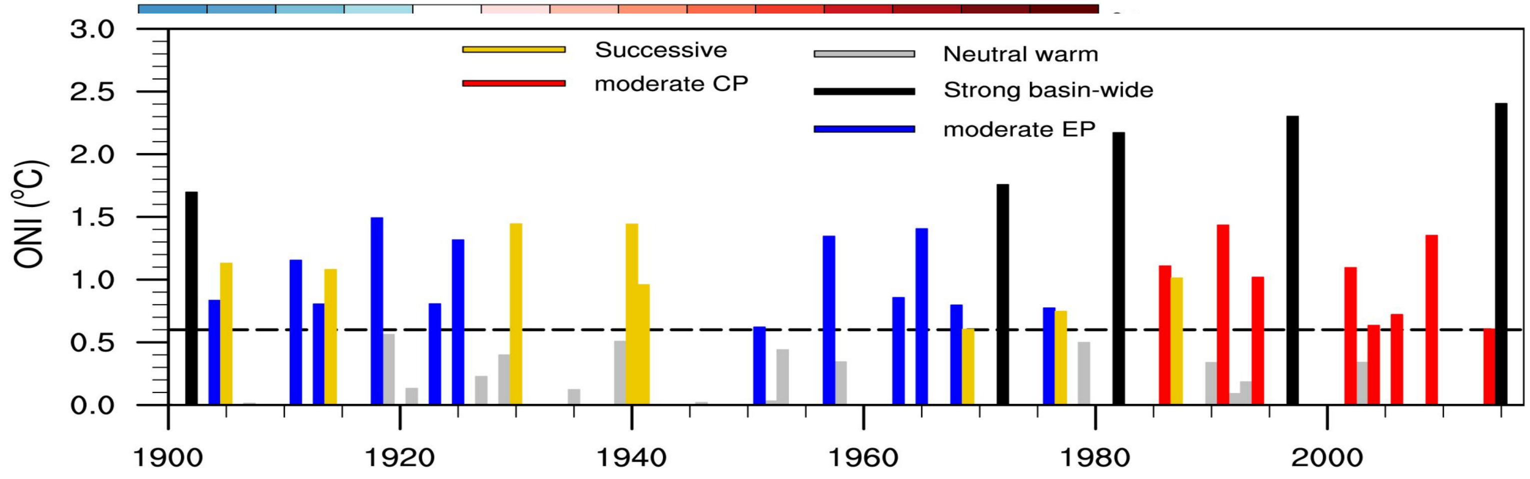
The projections from the CMIP5 models indicate that both the frequency and intensity of intense El Niño events will significantly increase if the projected central Pacific zonal SST gradients are enhanced. The results from the large-ensemble experiments of the CMIP6 CESM2 model support the observed linkages of ML-WP warming.



NINO3.4 SST anomalies normalized by the standard deviation (SD=1.0^{o}C).
Red solid dots (empty circles) mark the **19 major (20 minor) El Nino events**,
Blue solid dots (empty circles) mark the **18 major (18 minor) La Nina events**.



We classify 33 El Niño events from 1901 to 2017 through cluster analysis of their onset and evolution processes, resulting in three types of El Niño: super, moderate Eastern Pacific (MEP), and central Pacific (CP) events, each exhibiting distinct development mechanisms and varying global climate impacts.

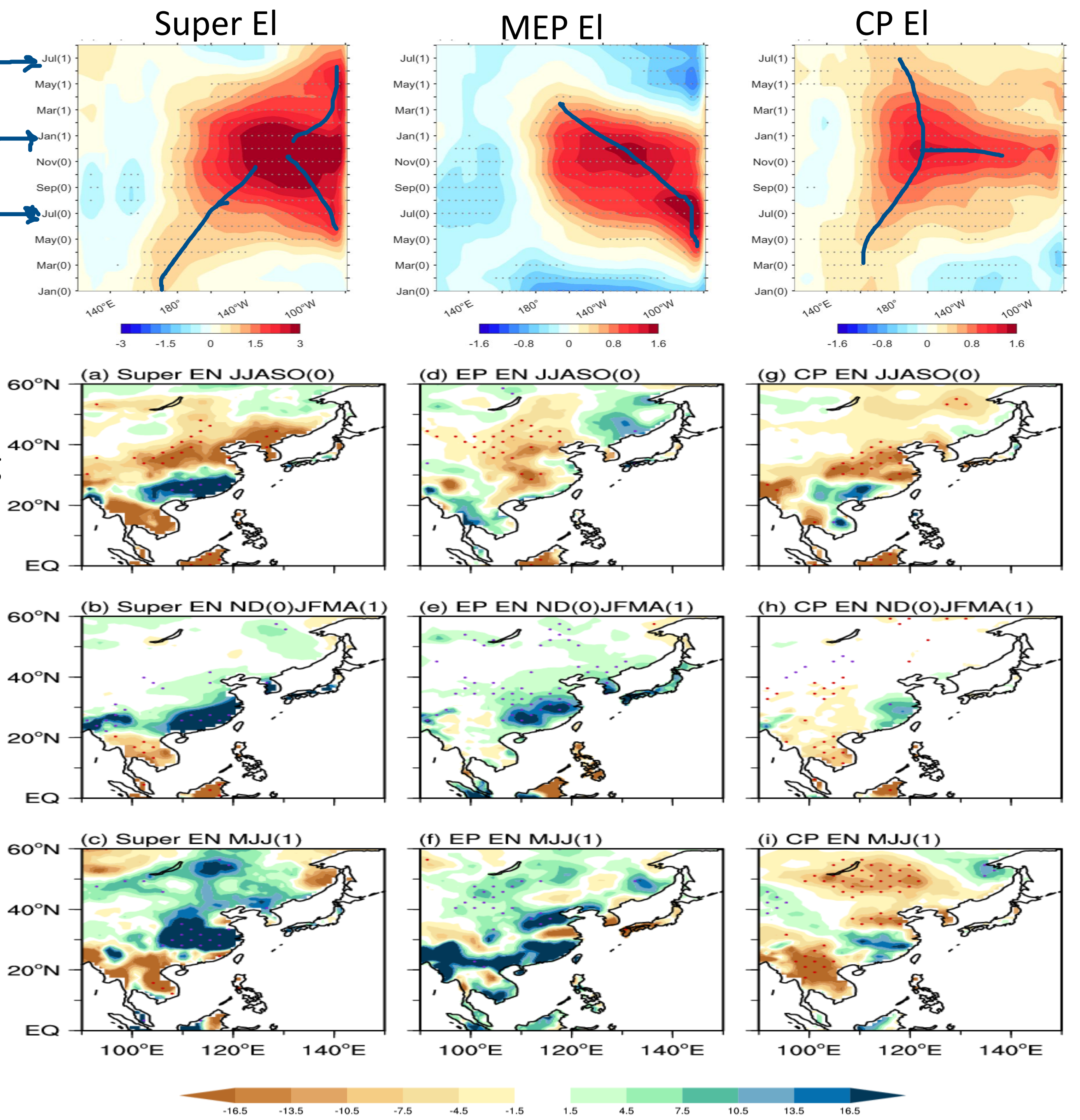


Since the 1970s, El Niño onset has shifted from the eastern Pacific to the western Pacific, leading to a more frequent occurrence of super and CP El Niño events

III, decaying

II. Mature

I Developing



I: Developing
JJASO(0)

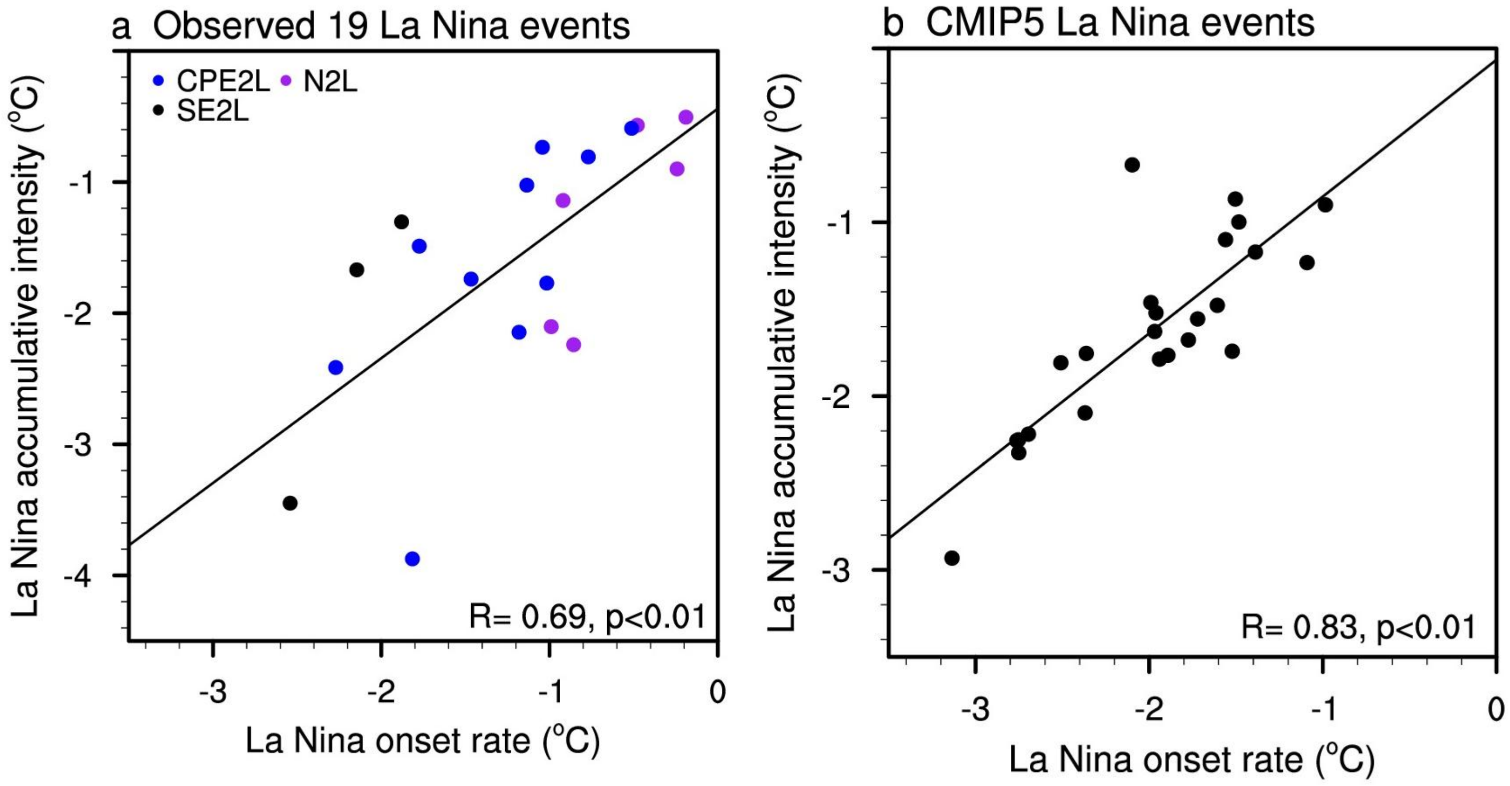
II: Mature
NDJFM(1)

III Decaying
MJJ(1)

Diversity dependent
Intensity-dependent
Phase-dependent

Domain: 10S-50N,
Check Philippines
precipitation.

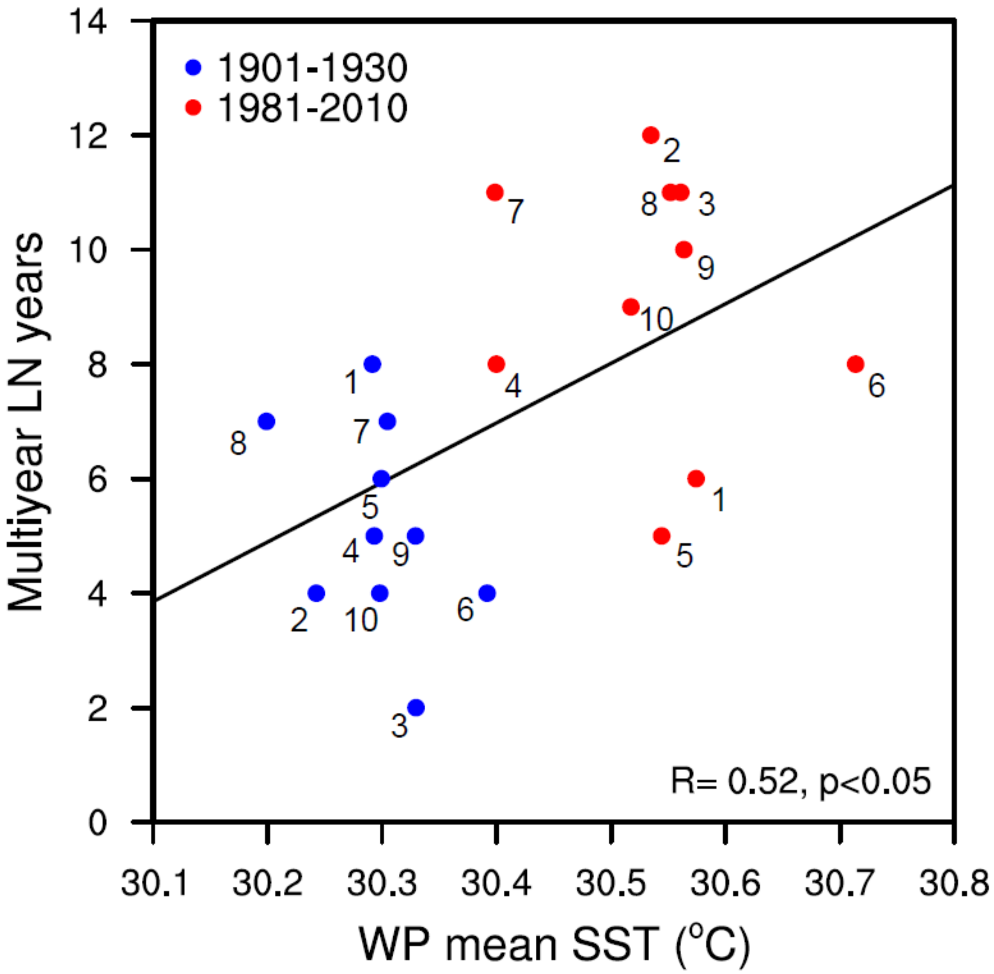
A precursor distinguishing Multiyear and single-year La Niña

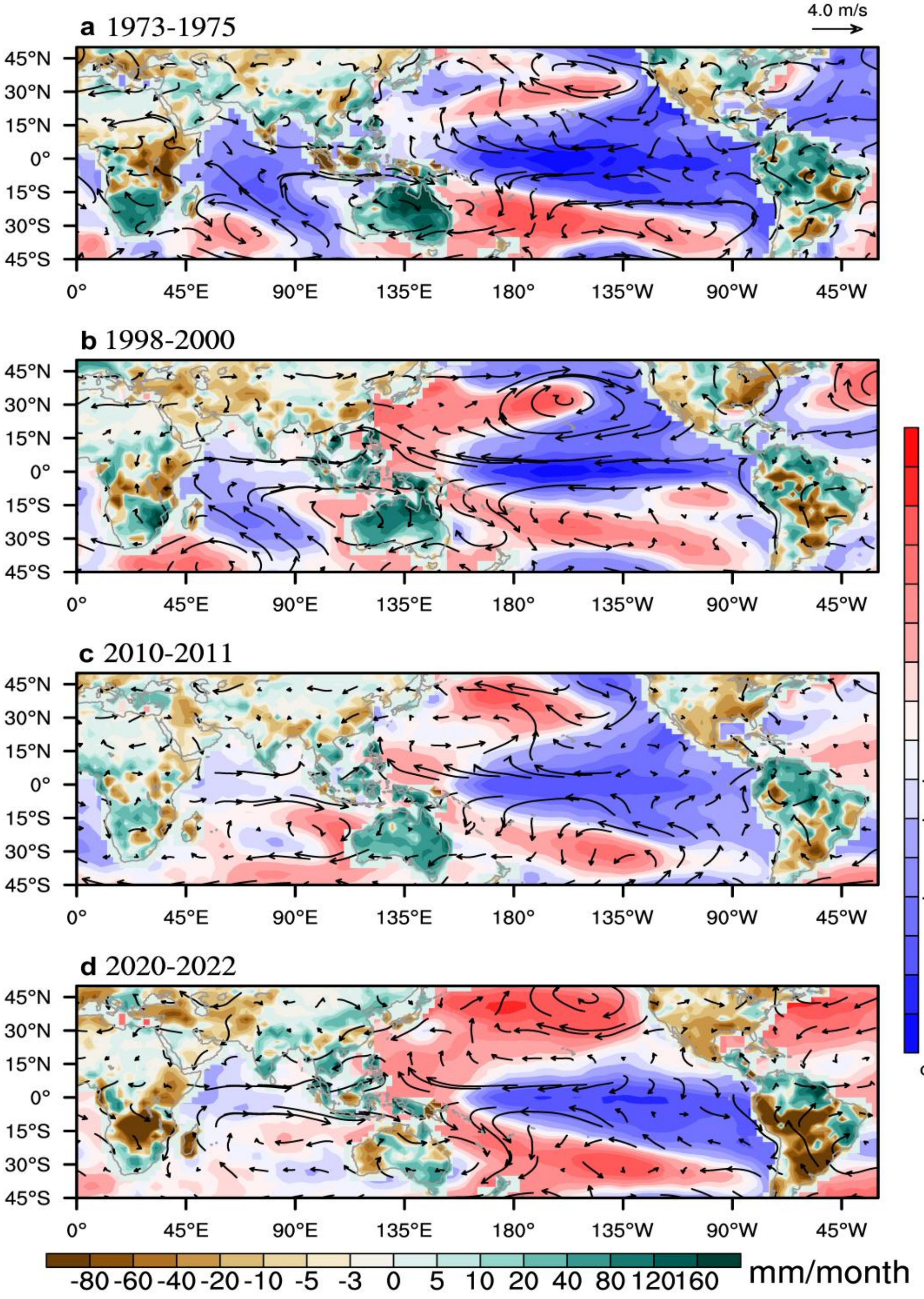


The Linkage between the La Niña onset rate and its accumulative intensity: (a) 19 La Niña events during 1920-2019. (b) eight CMIP5 models' historical runs and RCP4.5 and RCP 8.5 projections. The La Niña onset rate is represented by the SSTA tendency from March to October averaged over the central-eastern Pacific (5°S-5°N, 90°W-180°W). Each dot in (b) illustrates the averaged value derived from 24 individual model runs (eight models and three scenarios).

CESM2 large ensemble simulation supports the hypotheisis

Number of multiyear La Niña years significantly increases with rising WP SST in CESM2





Accumulative intensity measures La Niña severity

Climate anomalies associated with four extreme La Niña events

- Four extreme La Niña events generally induce similar precipitation anomalies in boreal winter (ONDJF)
- The 2010-11 event has a weaker influence in Africa due to the feeble Indian Ocean cooling and associated weak circulation anomalies.
- The 2020-22 event has notably different impacts over Southern Hemisphere

A unique feature of EASM: Seasonal mean anomalies have a limited value in representing hydrological hazards.

Floods in China during summer 2016:
The worst since 1998

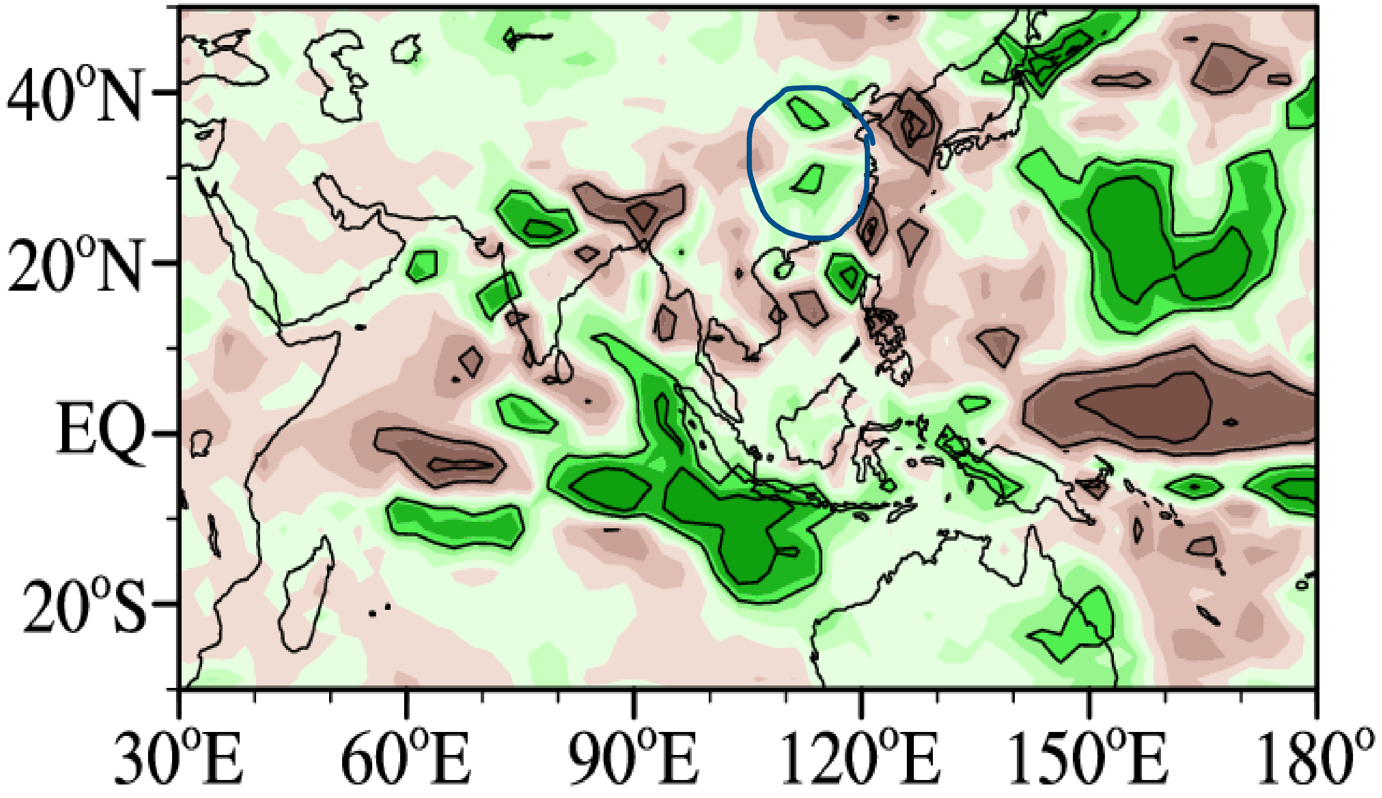
Guangxi floods: Liuzhou city is surrounded by the swollen Liujiang River, July 5, 2016. (**southwestern China**)

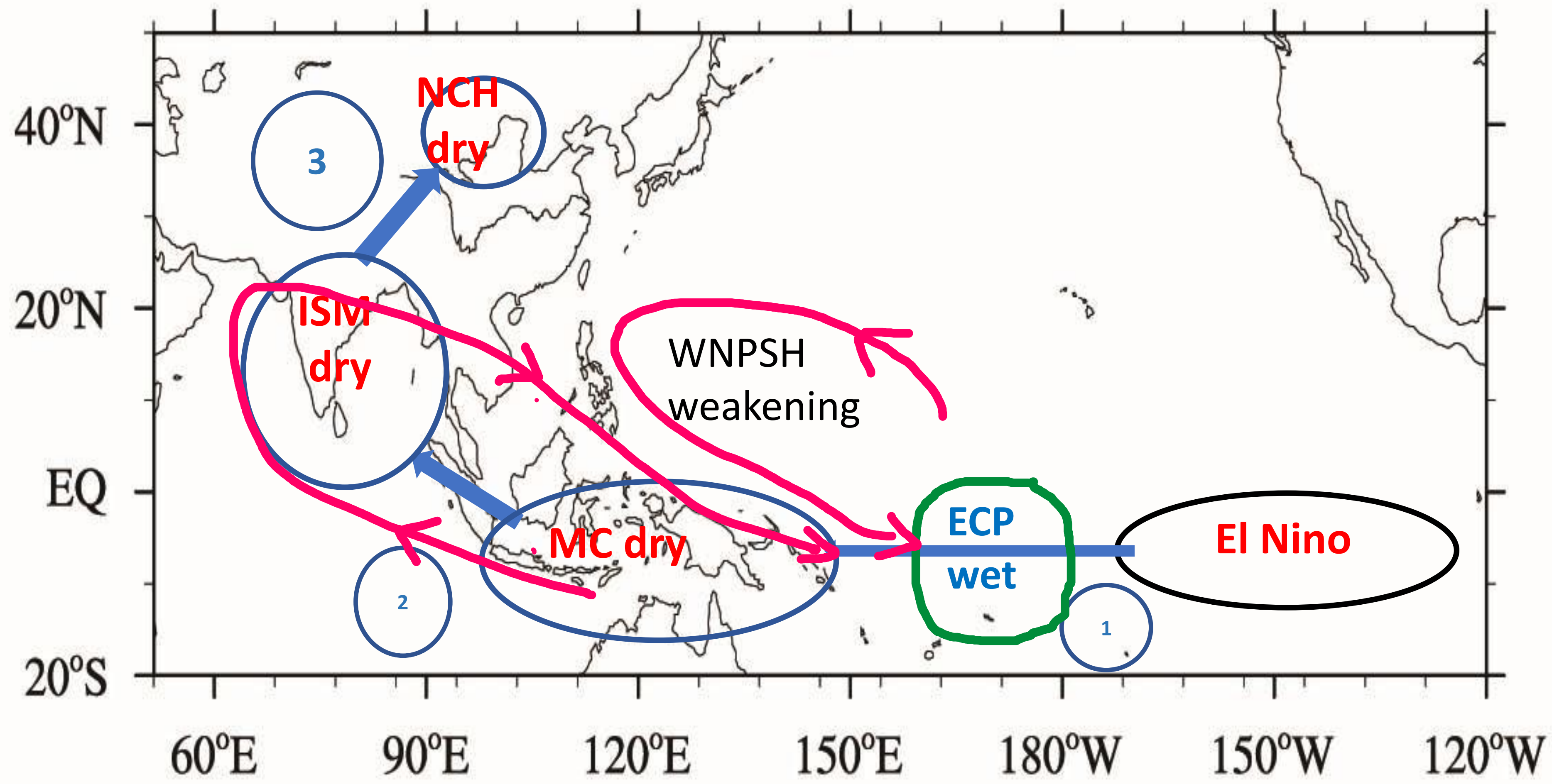
Wuhan floods: A flooded bridge in Wuhan, July 2 , 2016. (**central China**)

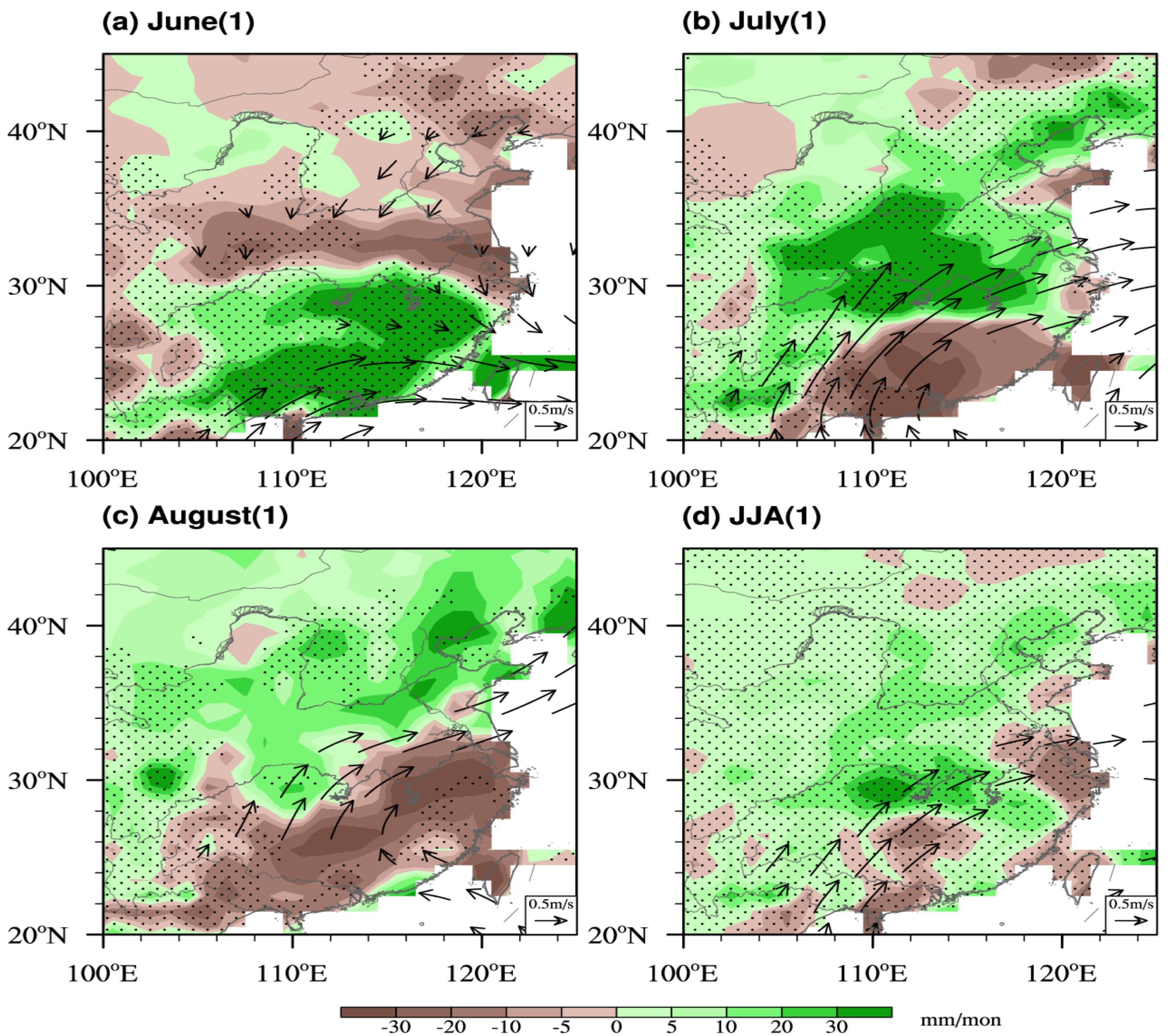
Beijing floods: Cars are submerged by floodwater in Beijing. July 20, 2016. (**northern China**)

From: http://edition.cnn.com/2016/07/23/asia/china-floods/index.html

However, the 2016 JJA mean anomalies show slightly wet.
Why?




40°N
20°N
EQ
20°S
60°E
90°E
120°E
150°E
180°W
150°W
120°W
NCH
dry
3
ISM
dry
WNPSH
weakening
MC dry
2
ECP
wet
1
El Nino



Seasonal migration of the Precipitation anomalies smooths out JJA (1) mean anomaly

Wang et al. 2017: Variable and robust East Asian monsoon rainfall response to El Niño over the past 60 years (1957-2016). Advance in Atmos. Sci., 34, 1235-1248.