# Variable and Robust East Asian precipitation response to El Nino

Bin Wang
University of Hawaii
ESMC NUIST

Acknowledge co-authors: Dr. Juan Li and Qiong He

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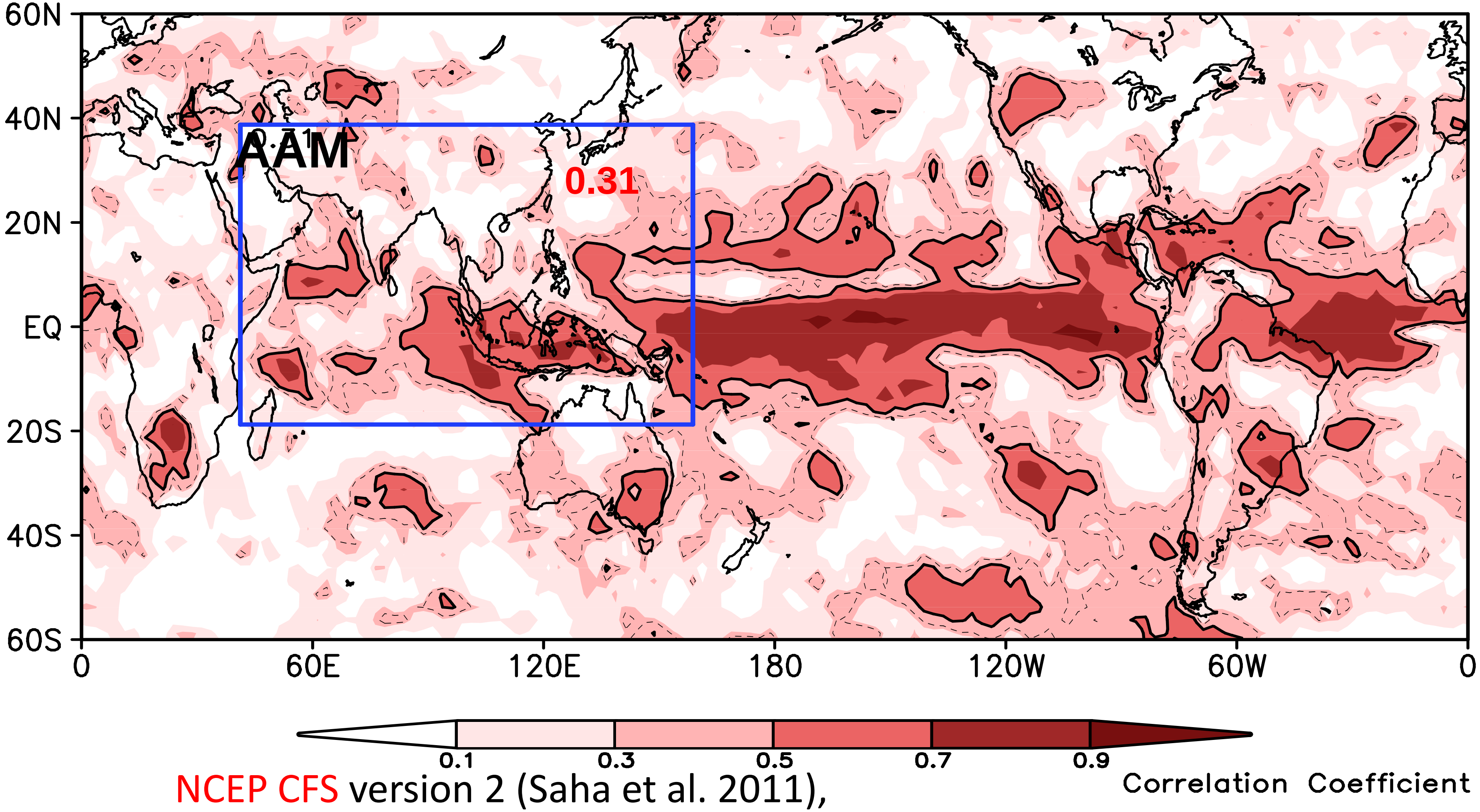
# Rainfall Prediction is one of the foremost challenges in climate science




Dashed contour: 0.35

Four dynamical models' MME prediction **Temporal Correlation Skill for JJA rainfall (1979-2010)**

NCEP CFS version 2 (Saha et al. 2011),
ABOM POAMA version 2.4 (Hudson et al. 2011),
GFDL CM version 2.1 (Delworth et al. 2006), and
FRCGC SINTEX-F model (Luo et al. 2005).

Wang et al. (2015)

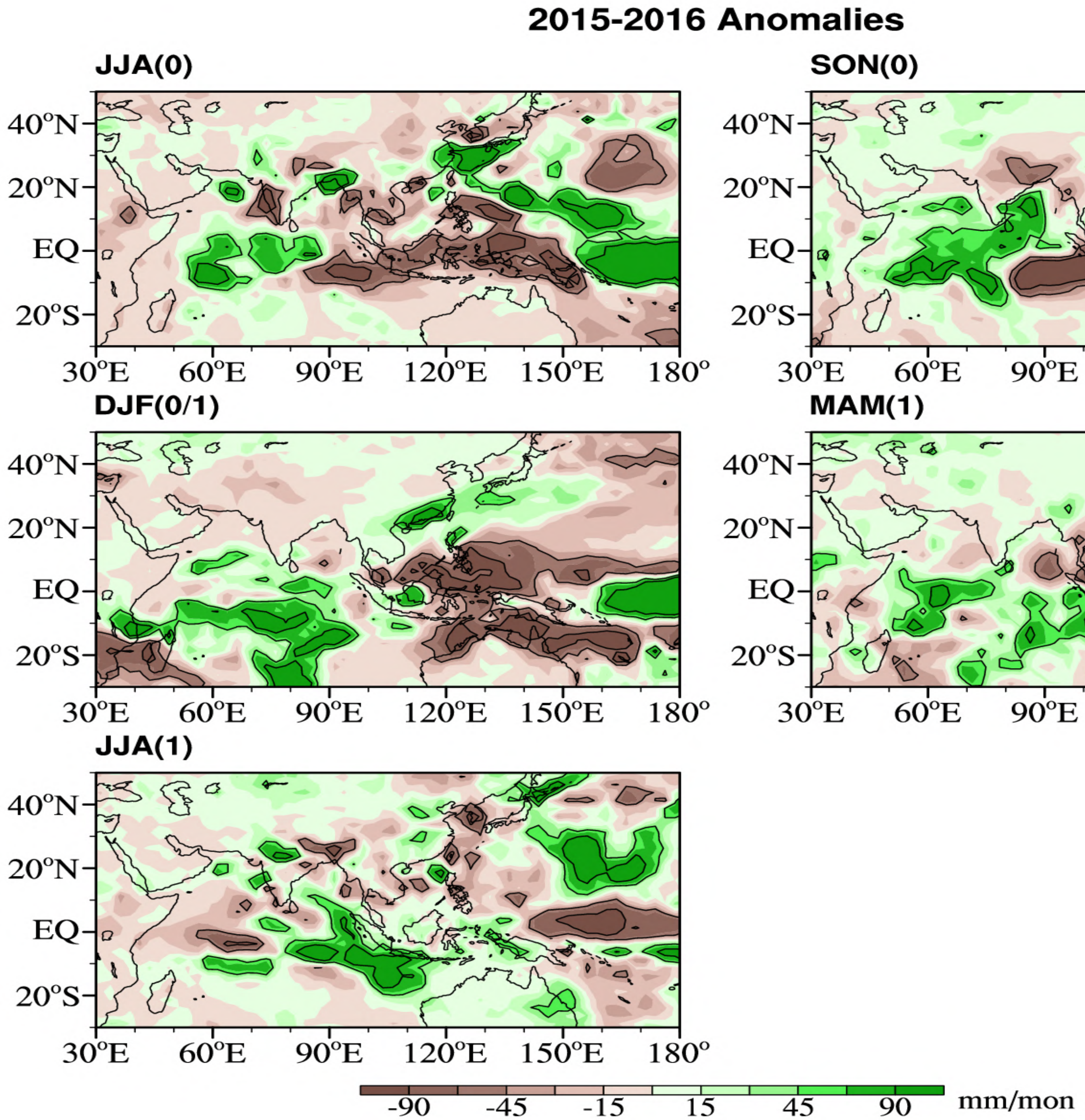
# Floods in China during summer 2016:
# The worst since 1998

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

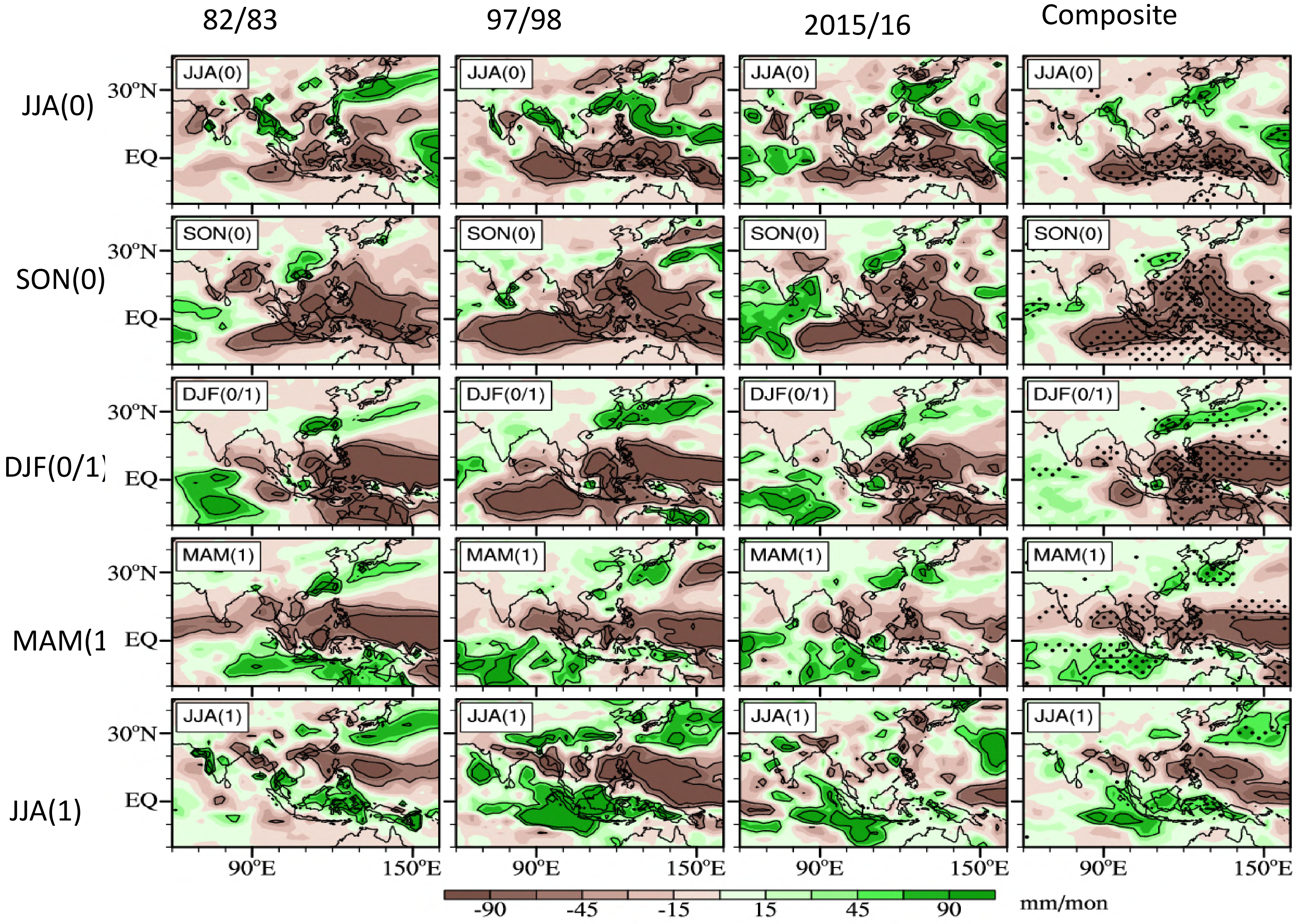
**Wuhan floods:** A flooded bridge in Wuhan, July 2 , 2016. (**central China**)

**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




**S**easonal mean precipitation anomalies GPCP precipitation data (1979-2016) were used.



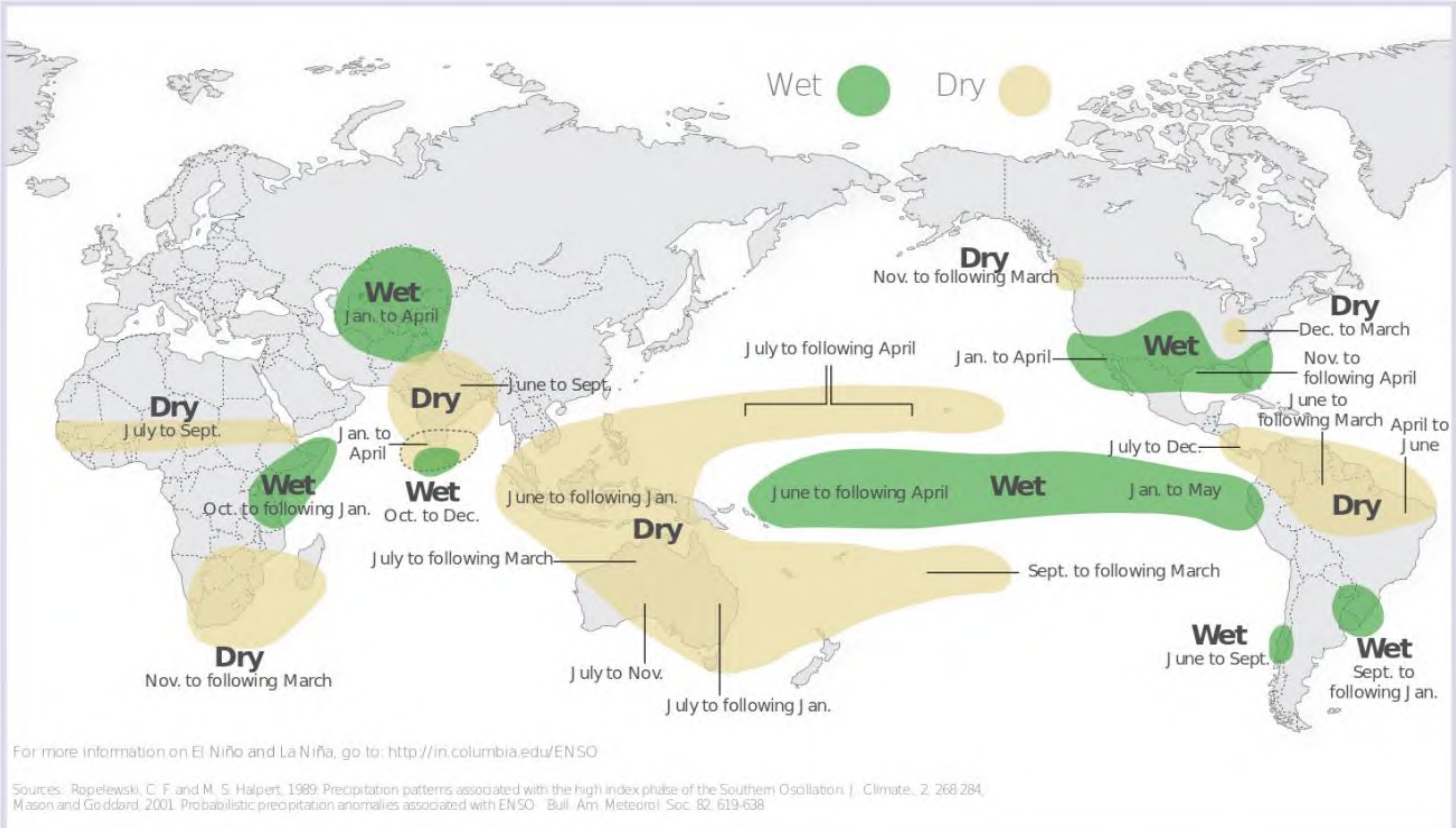

Considerable similarities, especially Maritime continent and Philippine Sea

Over EA, Enhanced rainfall along the East Asia subtropical front from SON(0) to MAM(1). But signals in JJA(0) and JJA(1) are weak.

Are these features typical to other El Nino events?

The areas where signal is less than "noise" over land are are blocked. GPCP data are used.

# El Nino impacts on global precipitation

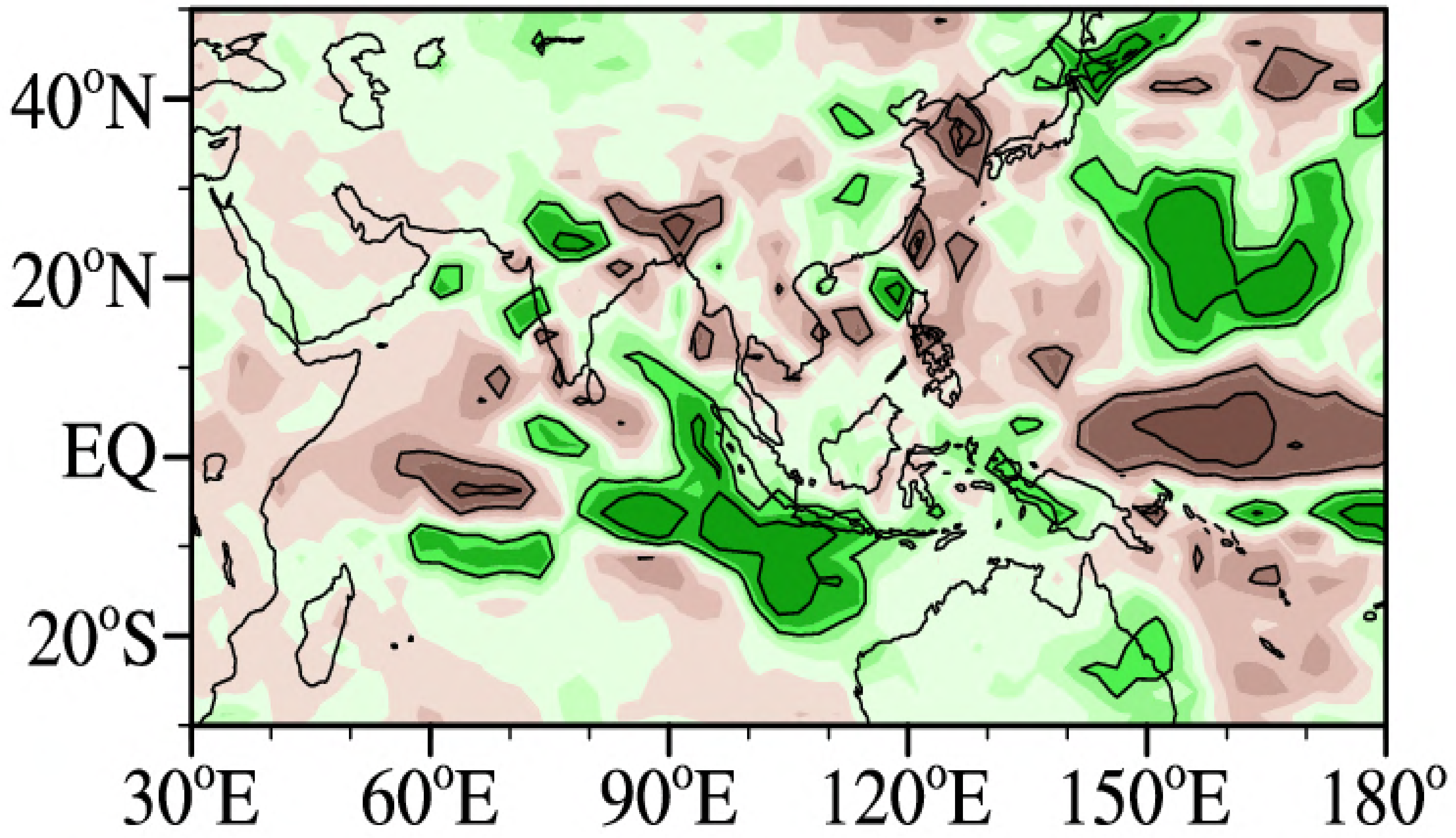


# Why are the El Niño impacts on EASM rainfall have not been well recognized?

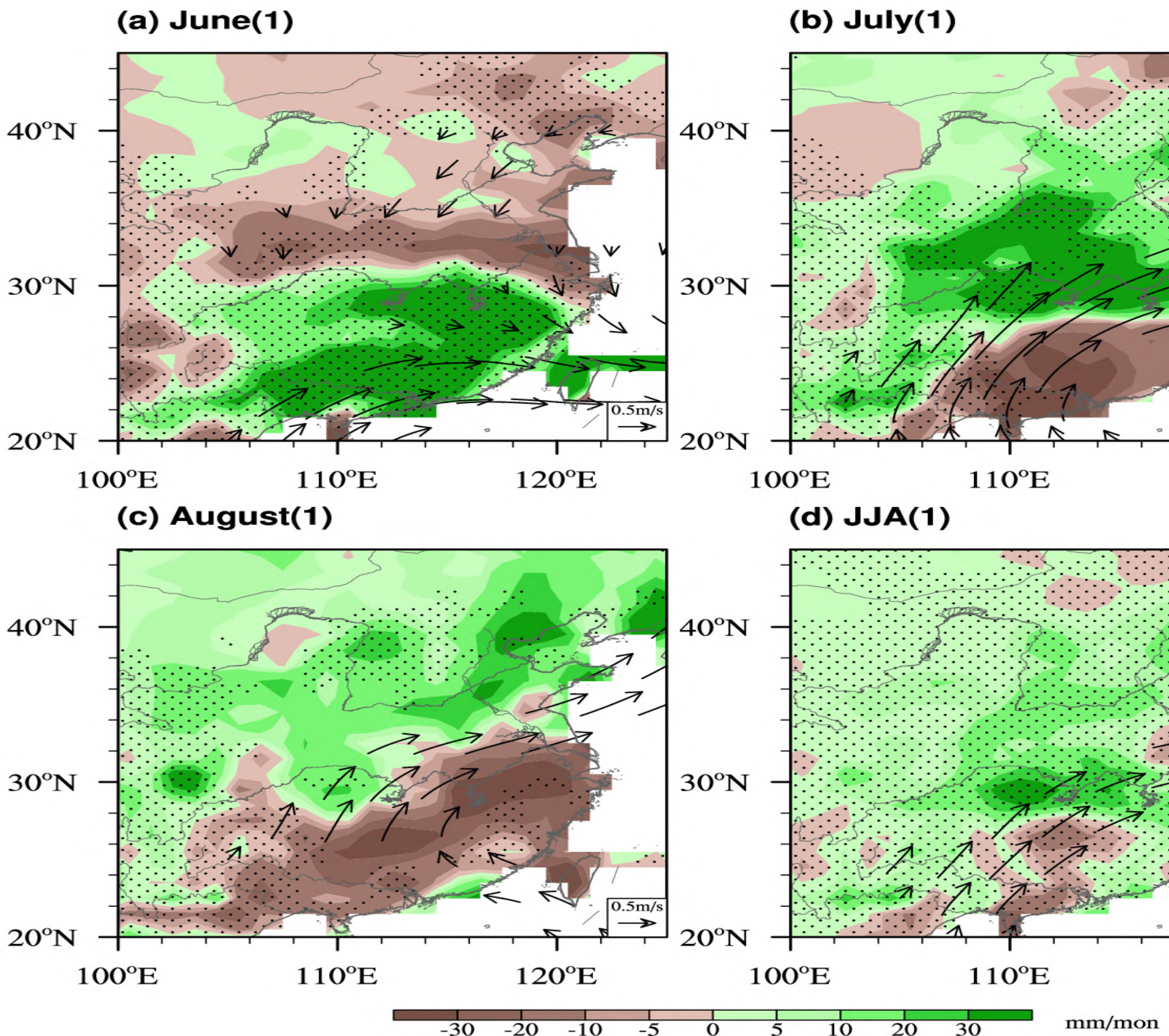
- 1. Seasonal migration of the anomalies  smooth out JJA mean anomalies
- 2. Variable Responses depending  on El Nino strengths
- 3. Indirect responses affected by AO interaction and mean flow effect (teleconnection)

- 1. Seasonal migration of the anomalies smooths out JJA mean anomaly

# 2016 JJA mean anomalies have a limited value in representing hydrological hazards

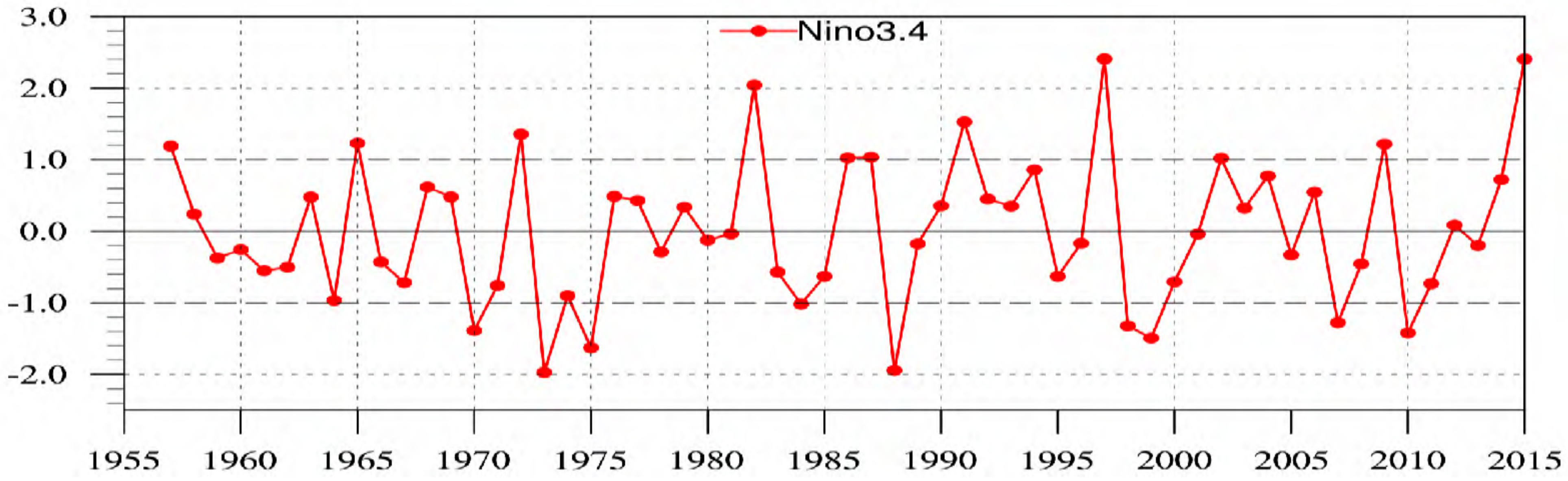


# Northward migration of rainfall anomalies weakens JJA mean anomalies



- 2. El Niño intensity and evolution diversity generates variable responses

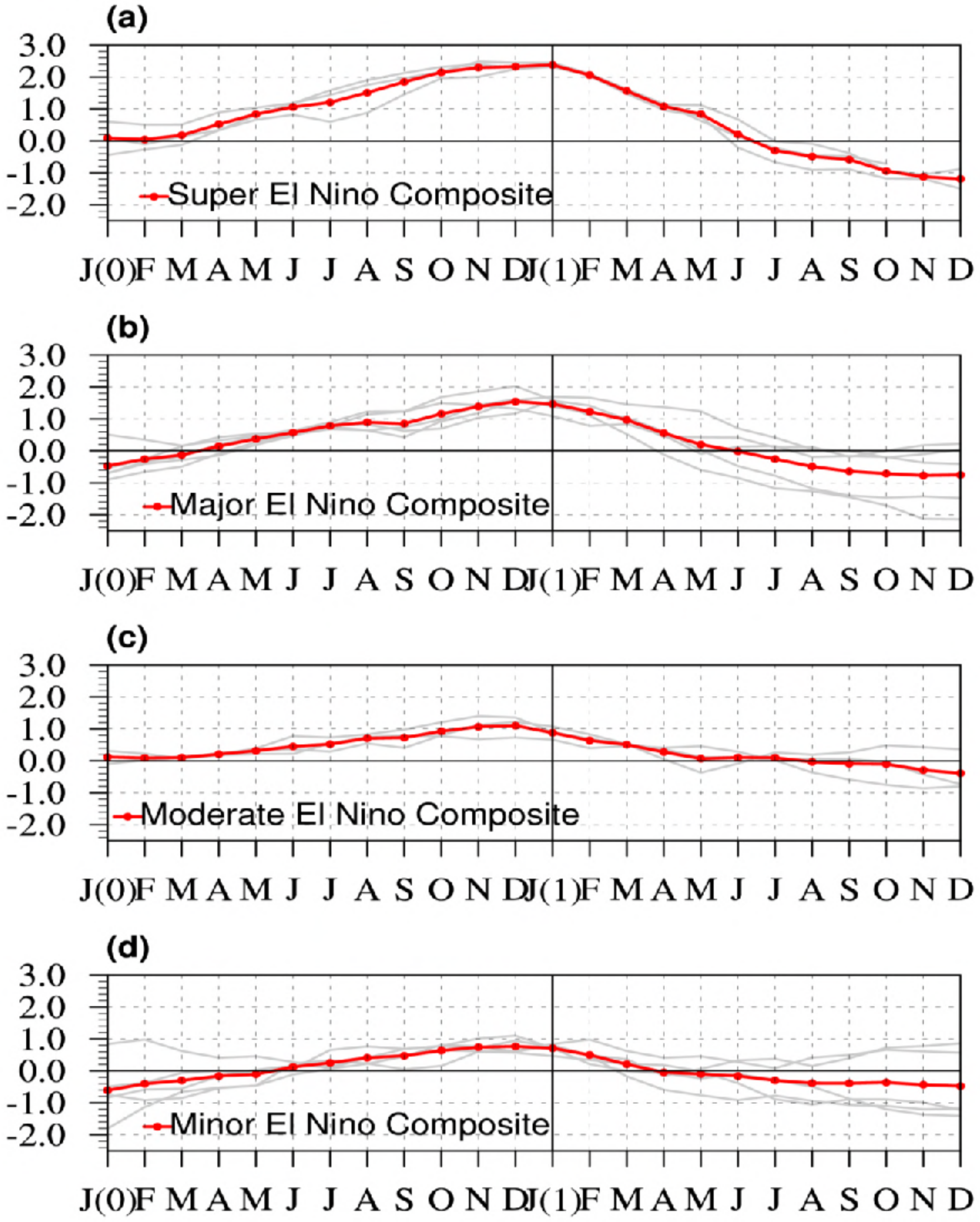
# ENSO anomalies seen from a Monsoon Year (June-May) perspective




Normalized Nino3.4 index based on monsoon year (Meehl 1987, Yasunari 1991)

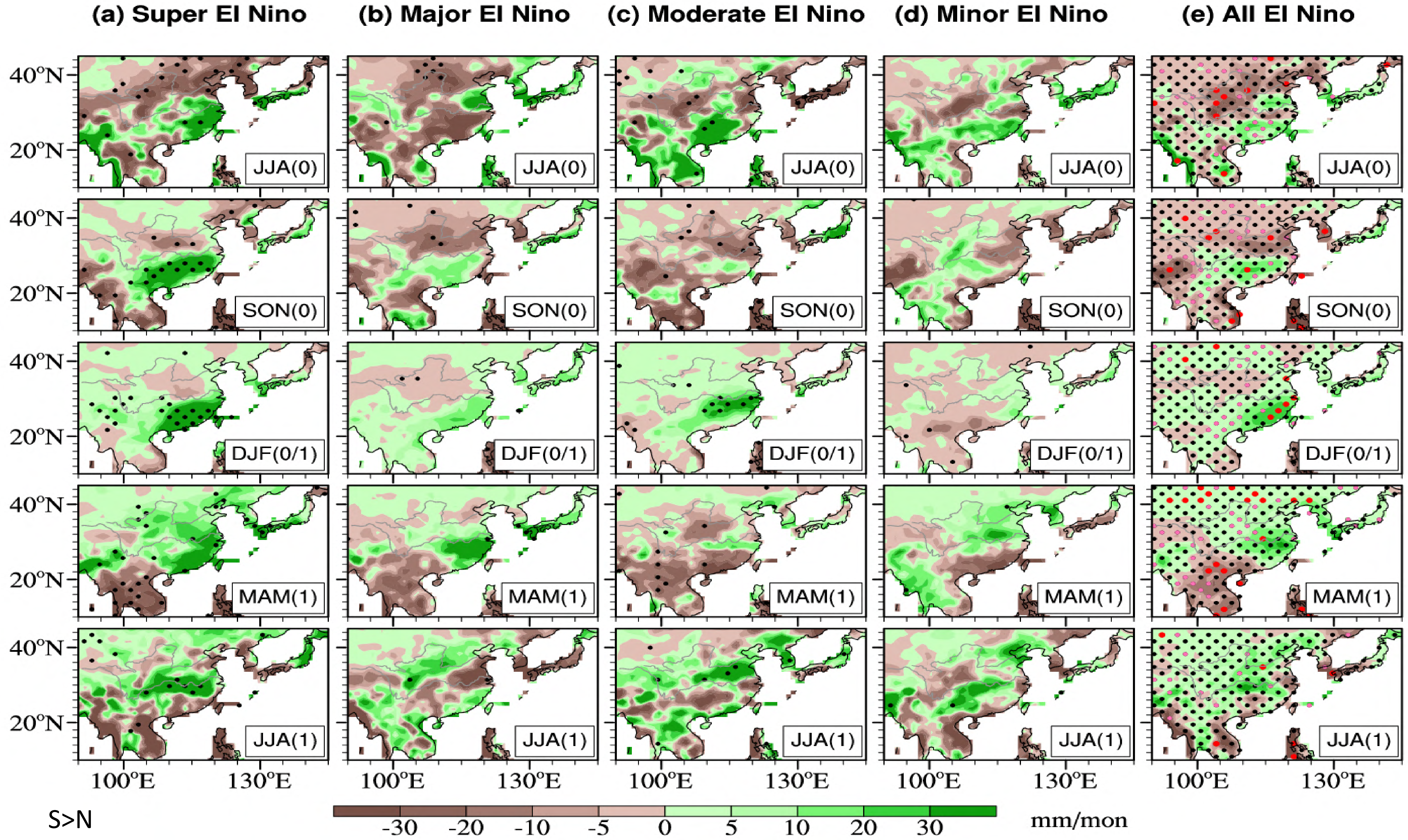
| Categories of El Nino events | years |
|---|---|
| Super El Nino (>2SD) | 1982, 1997, 2015 |
| Major El Nino (1SD~2SD) | 1957, 1965, 1972, 1991, 2009 |
| Moderate El Nino(0.7SD~1SD) | 1986, 1987, 1994, 2002, 2004 |
| Minor El Nino(0.5SD~0.7SD) | 1963, 1968, 1969, 1976, 2006 |

Monsoon-Year Nino 3.4 index measures the averaged El Nino intensity during the entire monsoon year.




Composite evolutions of Nino3.4 index (red curve) from Jan(0) to Dec(1) for (a) 3 super, (b) 5 major, (c) 3 moderate and (d) 5 minor El Niño events, respectively. The grey curves indicate the evolution of Nino3.4 index for each individual El Niño event. Combined HadISST and ERSST data were used.

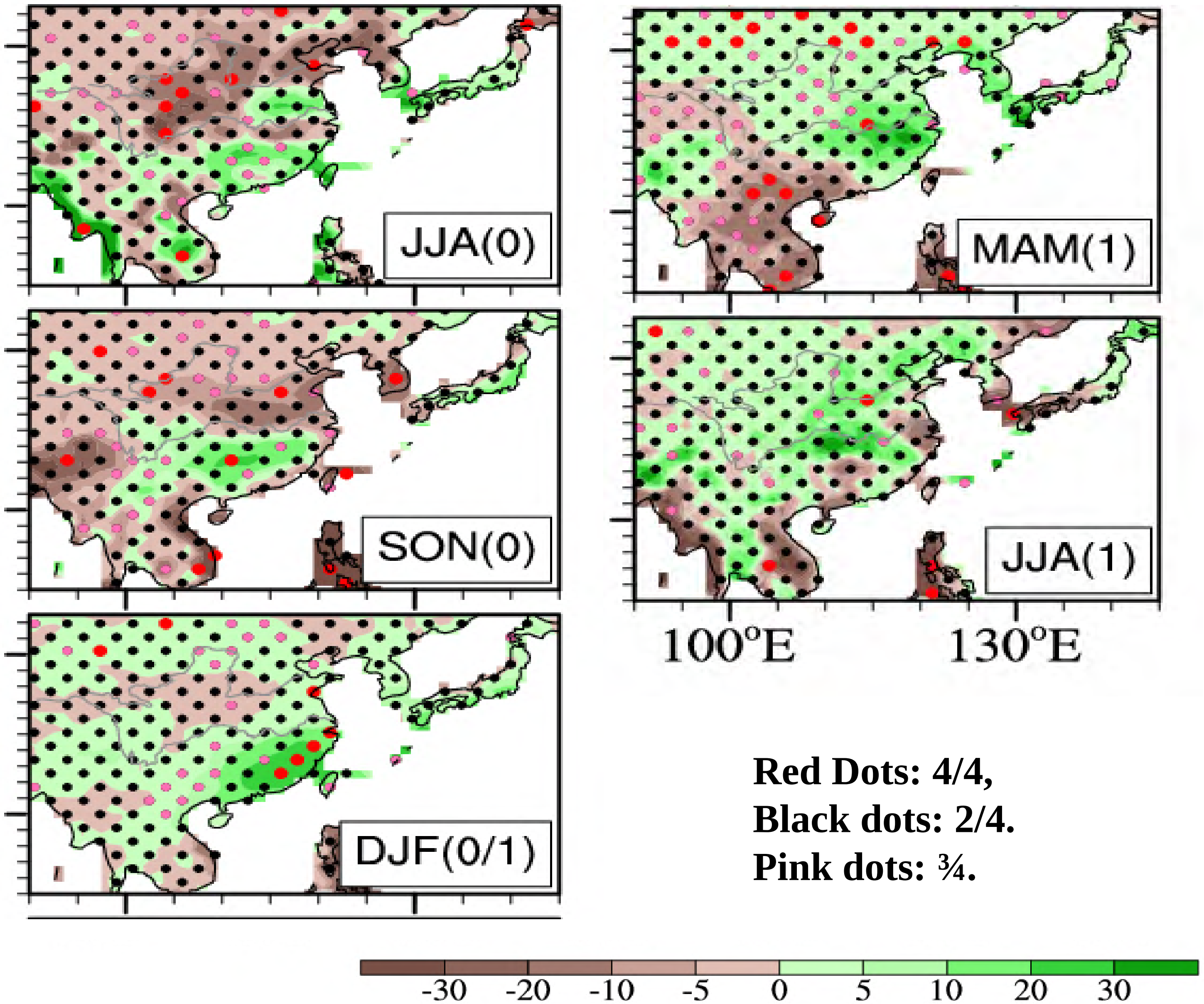
Evolution diversity during summer 0 and 1 increases with decreasing strength of El Nino.



(a) Super El Nino
(b) Major El Nino
(c) Moderate El Nino
(d) Minor El Nino
(e) All El Nino
40°N
20°N
JJA(0)
SON(0)
DJF(0/1)
MAM(1)
JJA(1)
100°E
130°E
-30
-20
-10
-5
0
5
10
20
30
mm/mon

S>N

# All El Nino composites




**Red Dots: 4/4,**
**Black dots: 2/4.**
**Pink dots: ¾.**

Precipitation anomalies associated with the different strengths of El Niño are remarkably variable.

Robust signals over EA are local.

JJA(0): dry central North China.

DJF (0/1): wet in Zhejiang and Fujian province.

MAM(1): dry over Guangxi and western Indo-China peninsula.

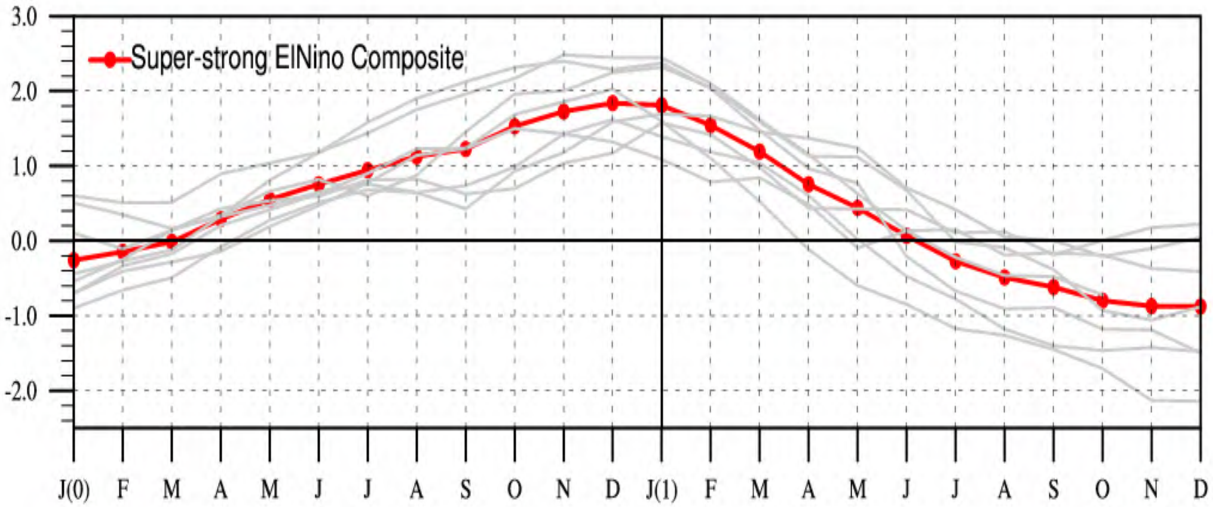
Can we identify more robust EAM responses?

further examine El Nino intensity-dependent signals

# Composite Nino 3.4 index

Strong El Nino (8)

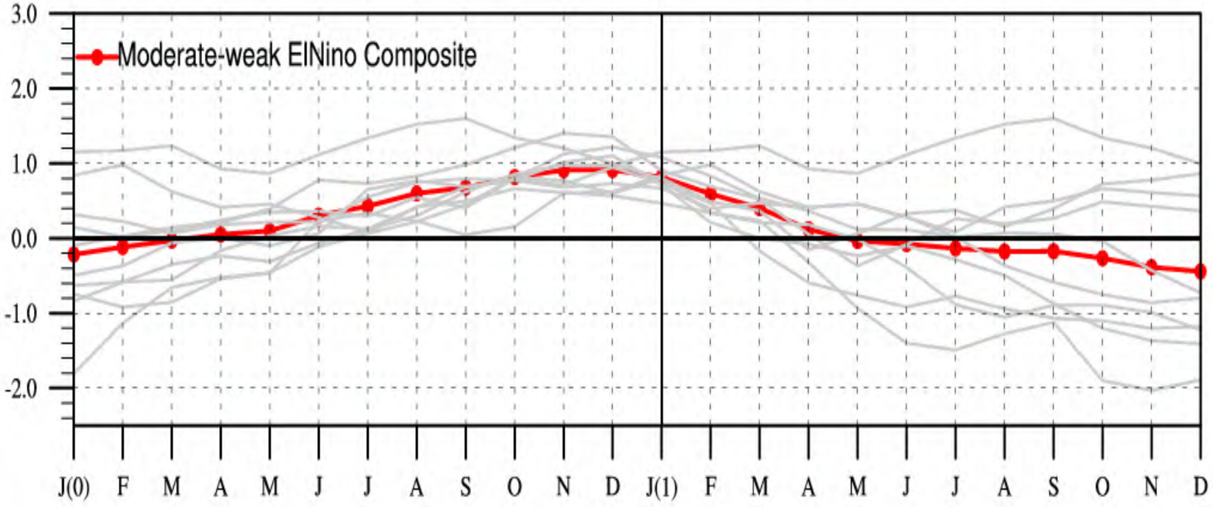
1957, 1965, 1972, 1982, 1991, 1997, 2009, 2015



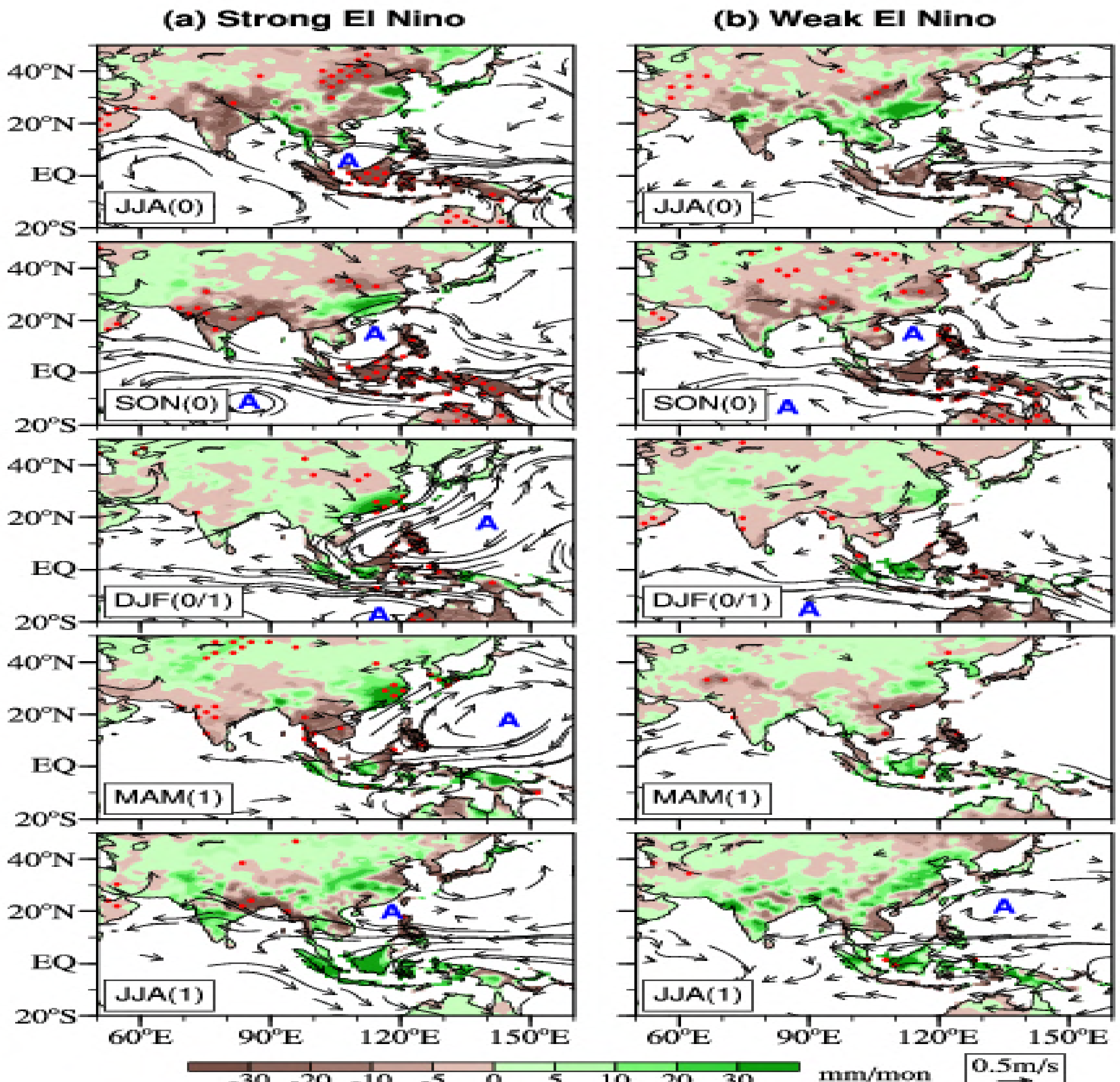

The 8 strong El Nino show similar evolutions except the magnitude.

Weak El Nino (10)

1986,1987, 1994, 2002, 2004 , 1963, 1968, 1969, 1976, 2006




Weak events have diverse evolution. Composite is meaningful for JJA(0), SON(0) and DJF (0/1).

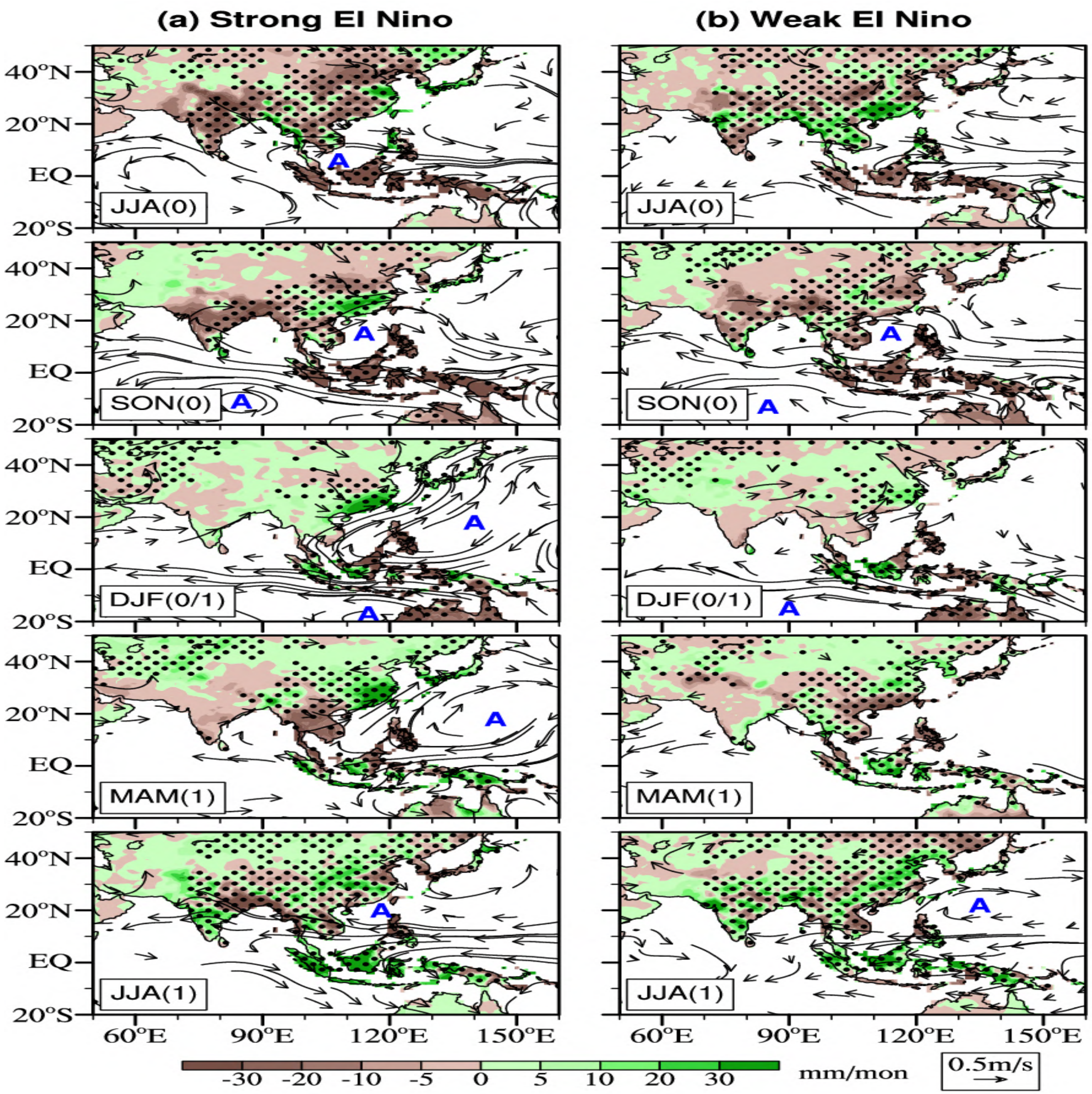



# Robust signals for Strong El Nino only

Summer (0): Central North China dry

DJF(0/1) and MAM(1): SE China costal region wet.

# 3. Indirect responses affected by AO interaction and mean flow effect (teleconnection)




# Robustness decreases from MC to India to EA

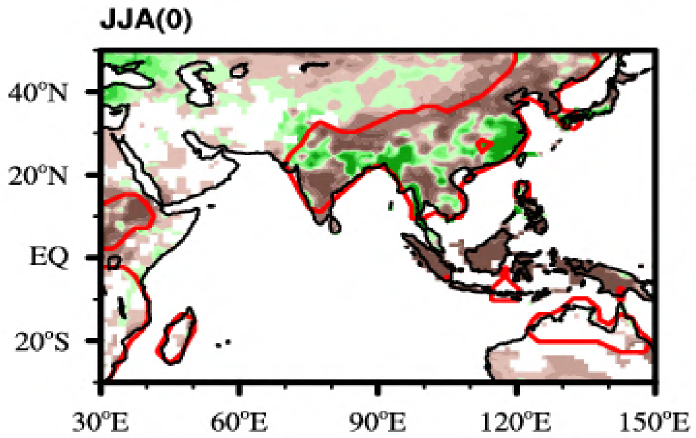
**Most Robust**: maritime continent and Northern Australia;

**Less robust**: India.

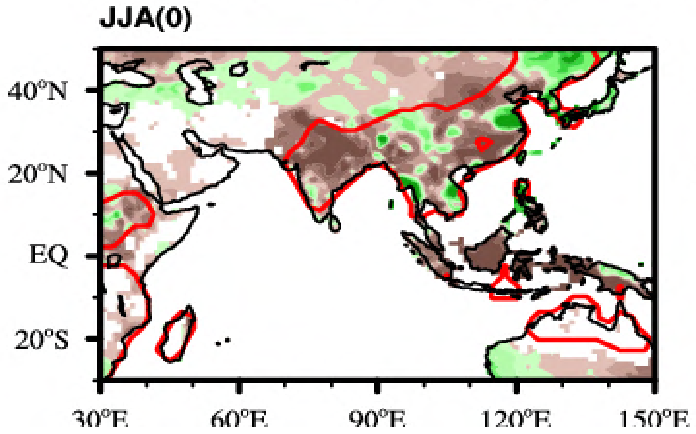
**Even less robust**: Northern China: Reduced rainfall in JJA(0) -SON (0), and increased rainfall in middle Yangtze River valley in JJA(1).

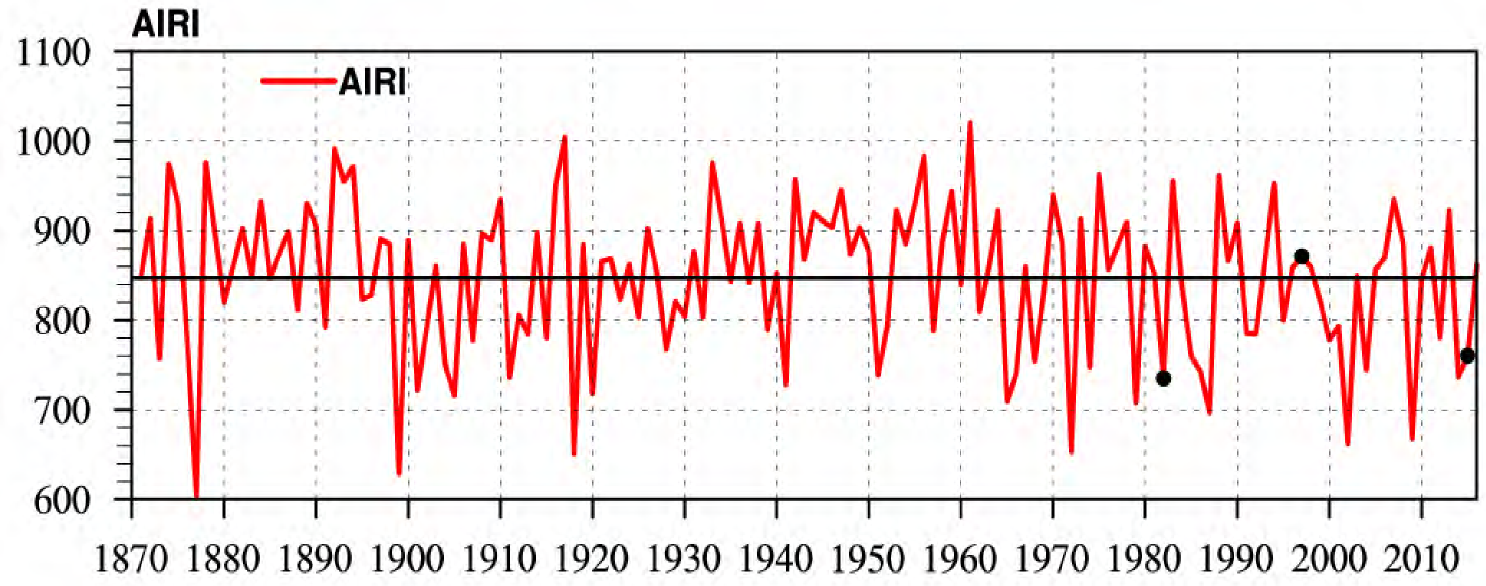
# Super El Nino does not necessarily cause super deficient ISM

3 super El Nino composite




5 strong El Nino composite



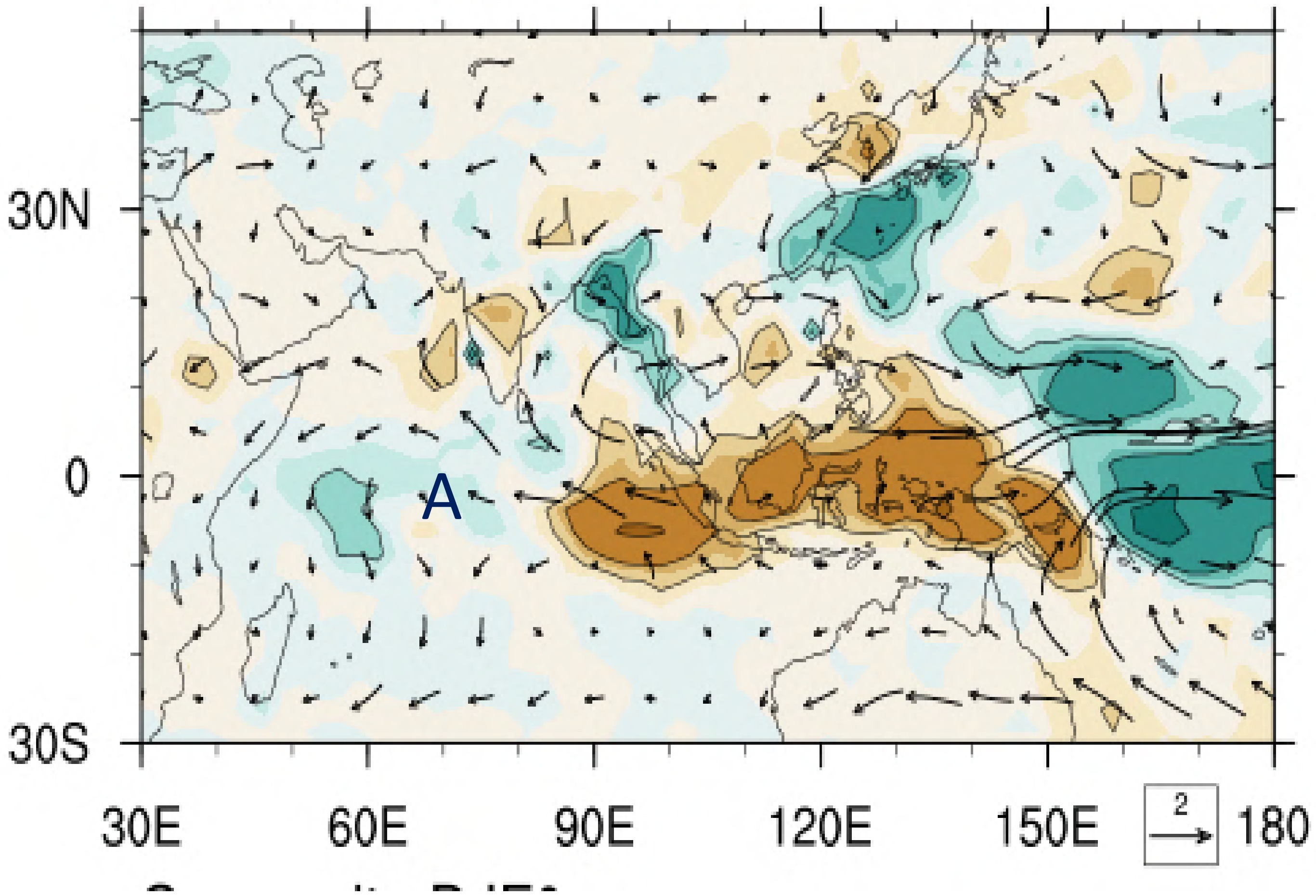




3 Super El Nino events do not cause terribly deficient ISM rainfall.

Supper and strong Ninos events show different impacts on ISM in JJA(0).

# Why super El Nino does not necessarily cause super deficient ISM

Composite JJA0 1982,1997,2015



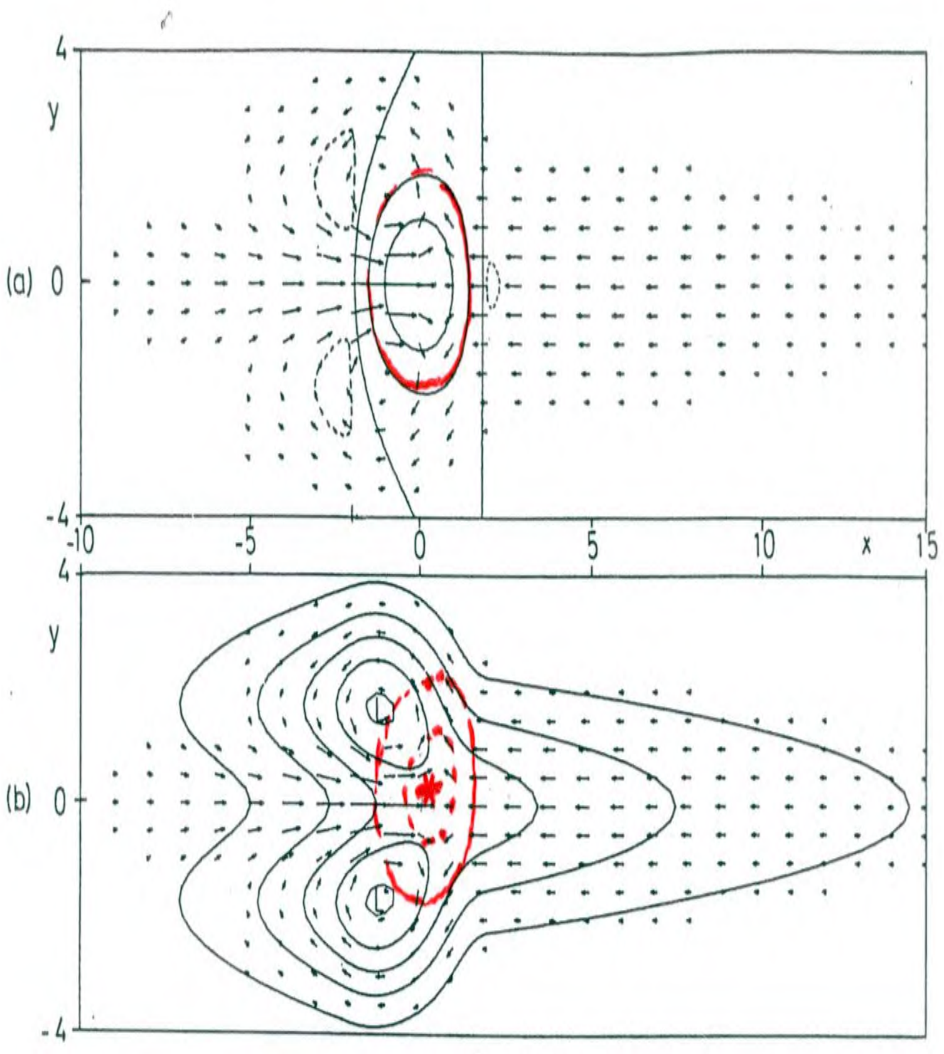

## Monsoon-ocean interaction in IO can offset El Nino 's impacts

--Equatorial Bjerkness positive feedback (IOD/IOZM) (Webster et al. 1999, Saji et al. 1999)

--Negative feedback by monsoon-induced anomalies (Meehl 1994, 1997, Lau and Nath 2000, Webster et al. 2002, Loschnigg et al. 2003).

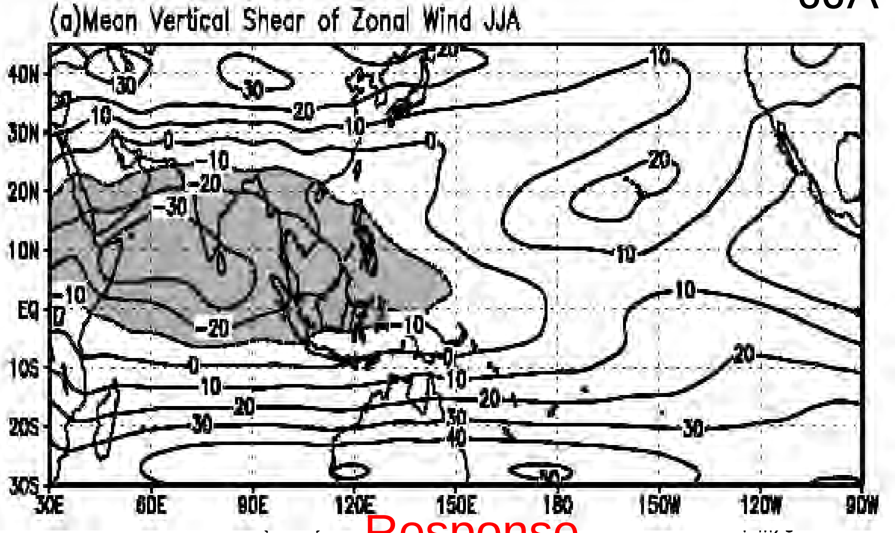
--Off-equatorial Rossby Wave-SST feedback either positive or negative, depending on background annual cycle (Wang et al. 2003)

# Why is the response to ENSO forcing is asymmetric about the equator?

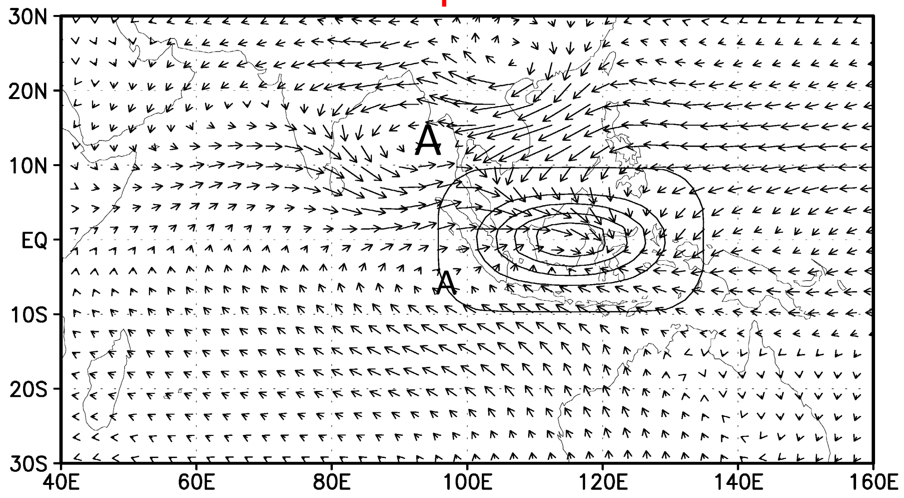



Easterly vertical shear

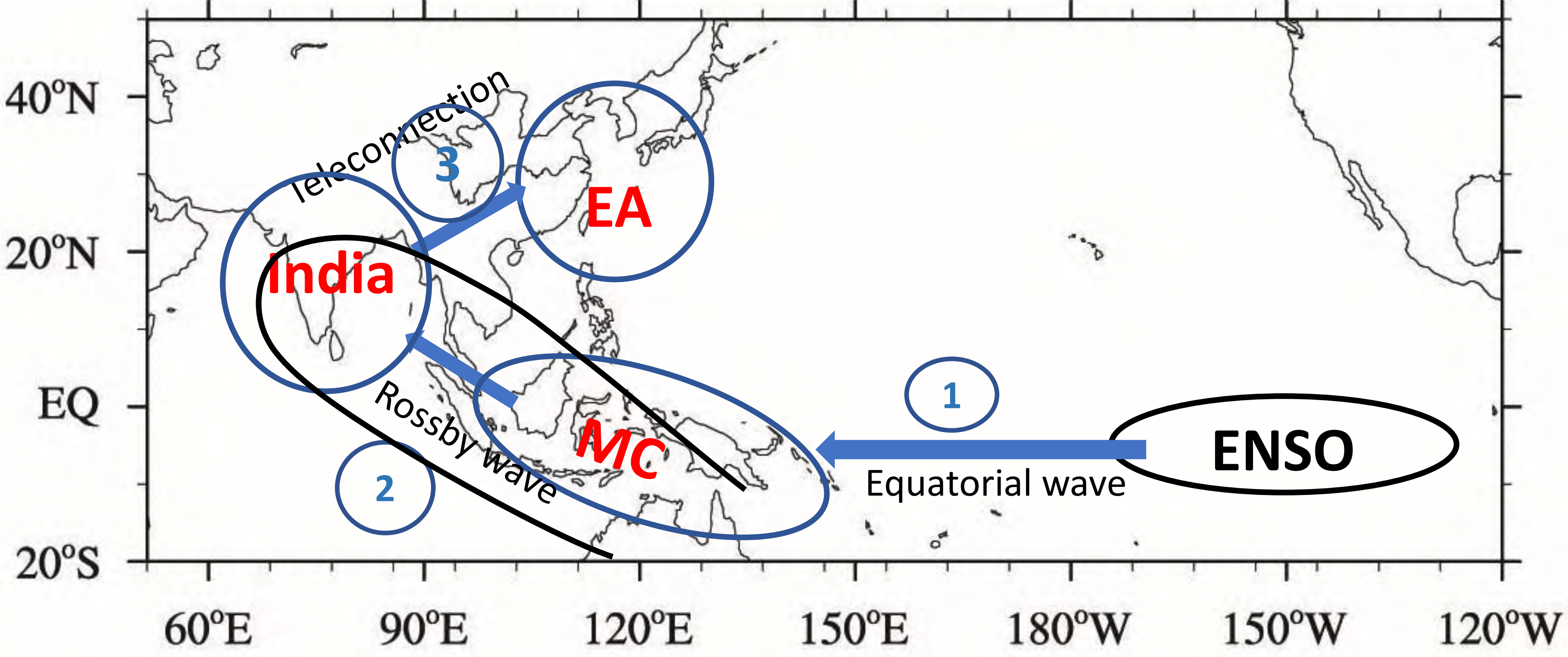
JJA




Response



# EA response during an El Nino developing Summer



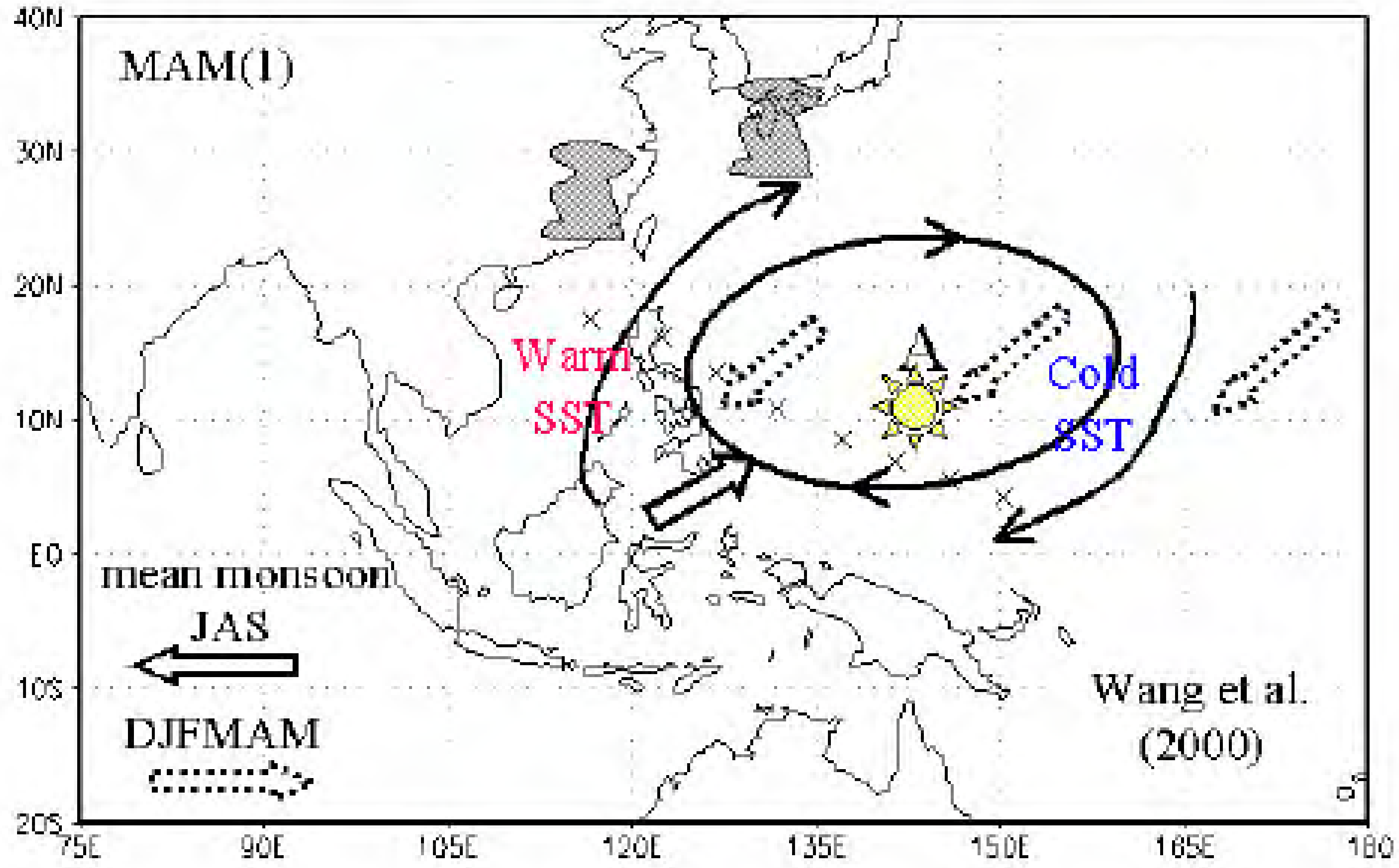

(1). Most robust impacts over MC and a less robust ion the Indian monsoon. Why?

- ❖ Efficient teleconnection along equatorial wave guide.
- ❖ Monsoon-ocean interaction offsets ISM response (Lau and Nath 2000; Saji et al. 1999; Webster et al. 1999; Wang et al. 2003)

(2). The northern China response to the El Niño is more variable than the Indian summer monsoon response. Why?

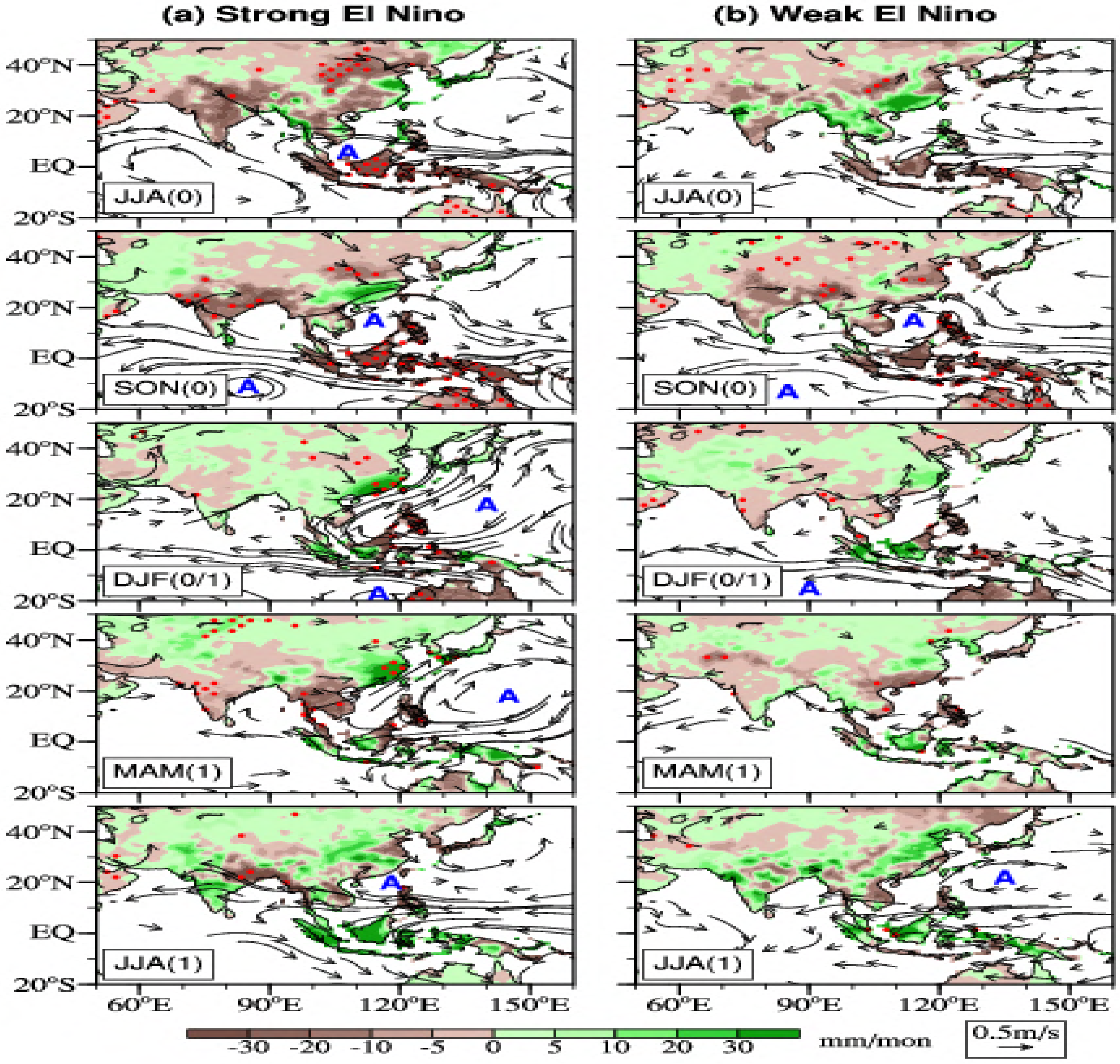
- ❖ Teleconnection from ISM to EASM: Silk road (Enomoto et al. 2003); Circum-Global Teleconnection (CGT) (Ding and Wang 2005) depend on mean flows

# EA response during an decaying phase of strong El Nino




Monsoon-ocean interaction in the WNP maintain WP AC anomalies, which provides a bridge for “delayed” impact of El Nino to EASM.

WNP Subtropical High and Indo-Pacific SST coupled Mode



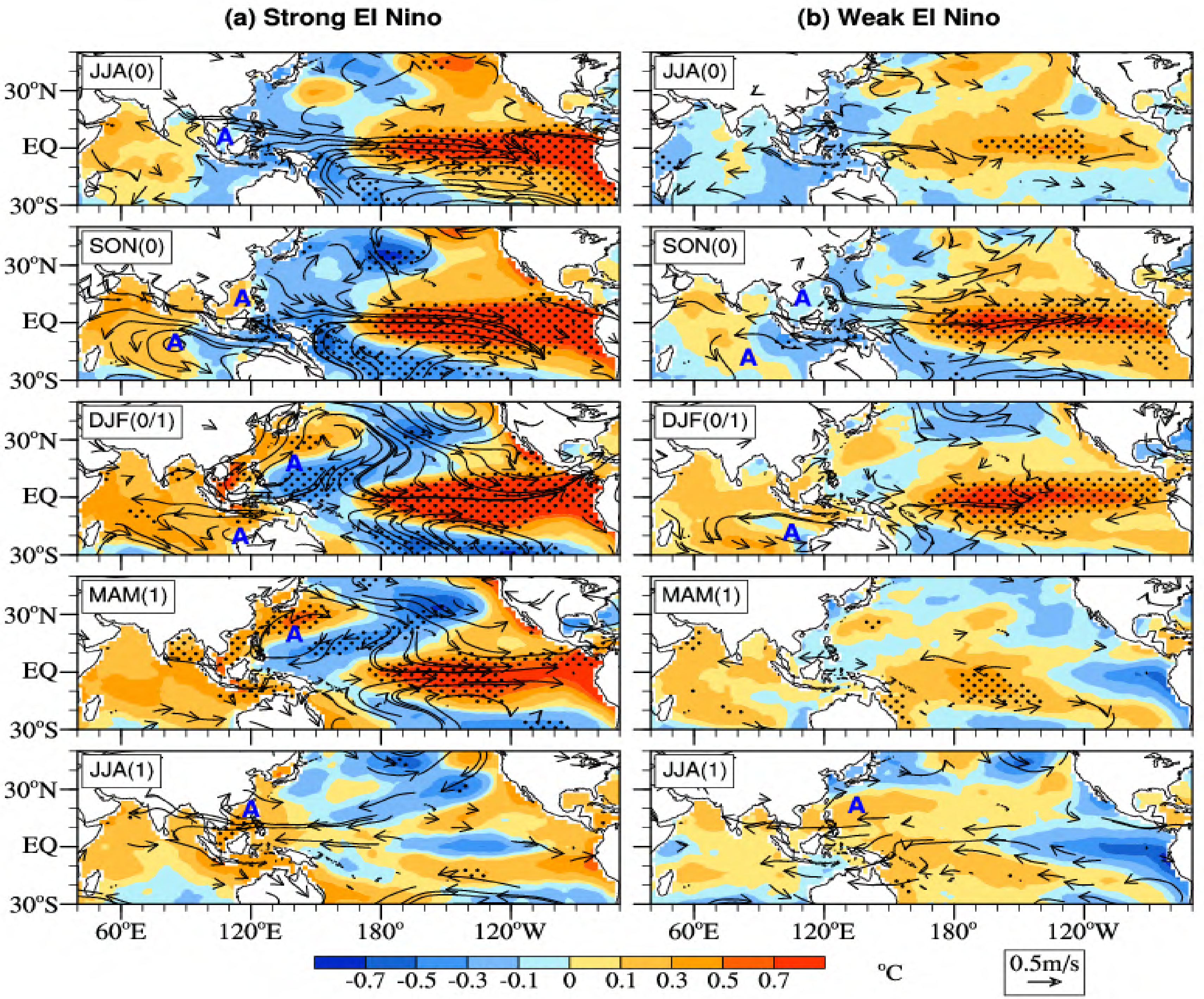

# Different impacts between strong and weak El Ninos

Persistent WPAC anomaly is responsible for the wet southern China from DJF(0/1) to MAM(1).

The WPAC anomaly occurs during the SON(0), further develops and expands eastward during DJF(0/1) and MAM(1), and weakens but maintains to JJA(1).

Only strong El Nino can excite persistent WPAC that persists into JJA (1).

Why?



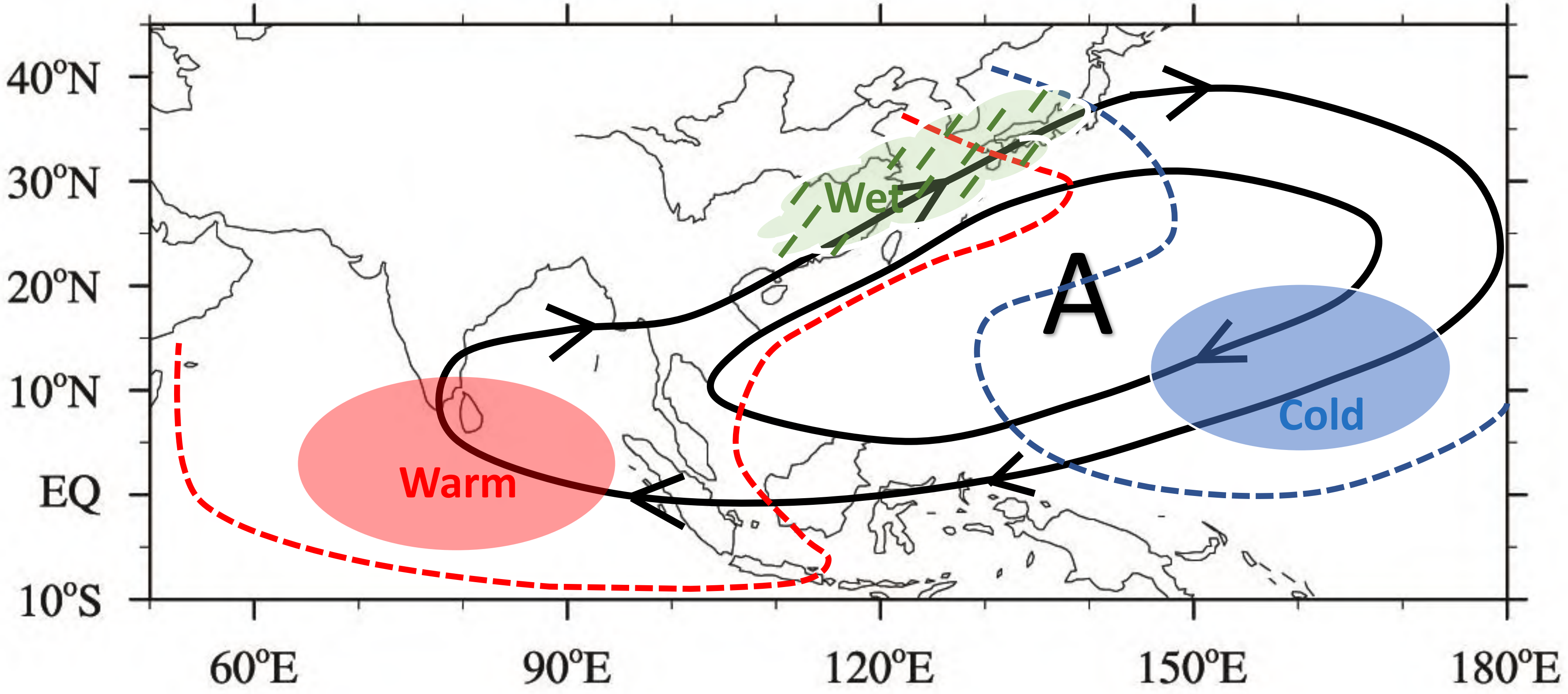

During strong El Nino, the WNP AC is coupled with a dipole SSTA in mature and decay phases, with cold SST to the E-SE and warm SST to the W-NW of the AC center.

**signal>SD (dots)**

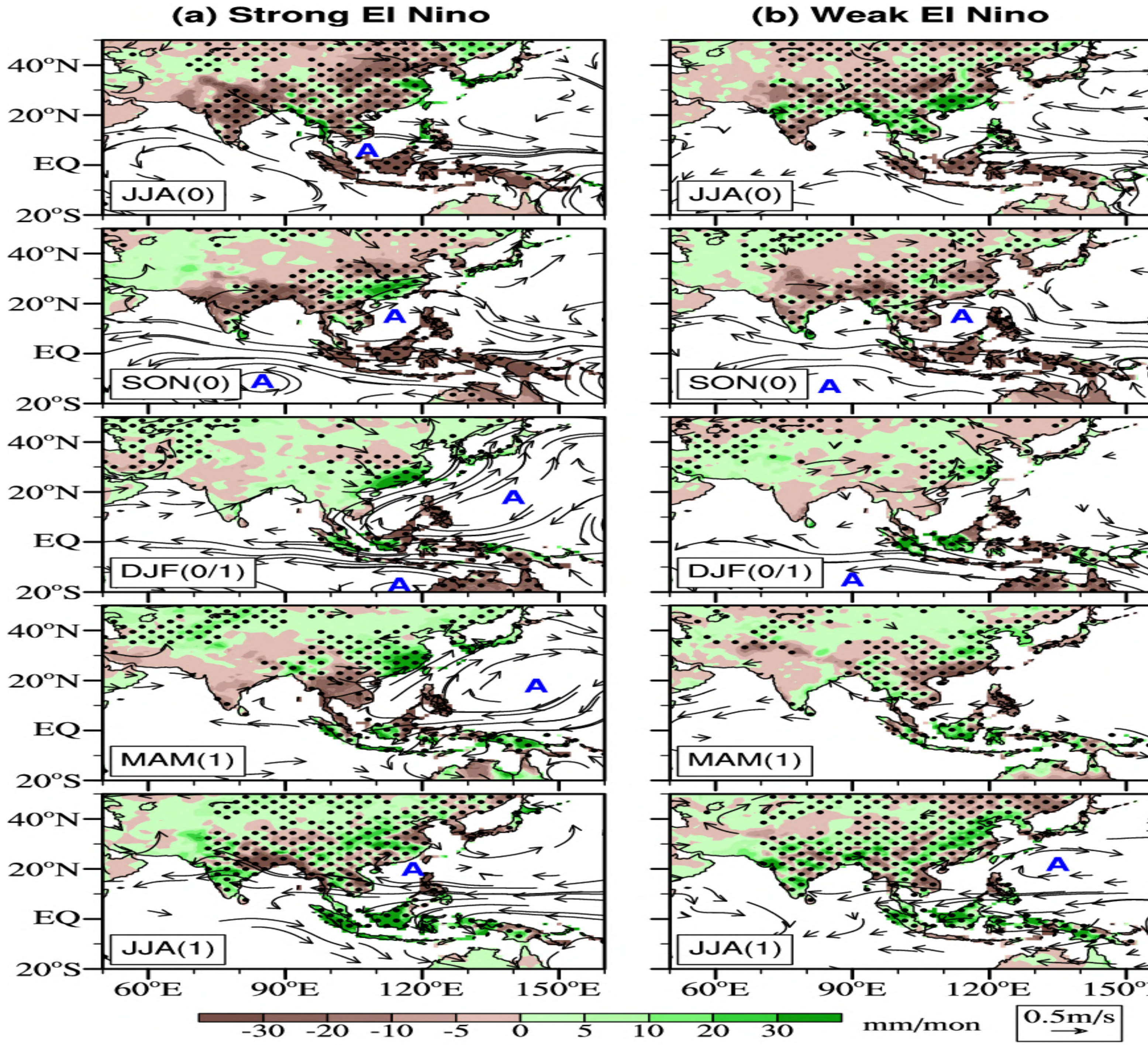
During strong El Niño events, the coupled WPAC and SST dipole anomalies maintains the WPAC, providing a prolonged enhancement of EA subtropical frontal precipitation

(Wang et al. 2000; Lau and Nath 2003; Lau et al. 2004; Lau and Wang 2006; Chowdary et al. 2010, Xiang et al. 2013; Du et al. 2009, Xie et al. 2009, Wu et al. 2009, Xie et al. 2016)

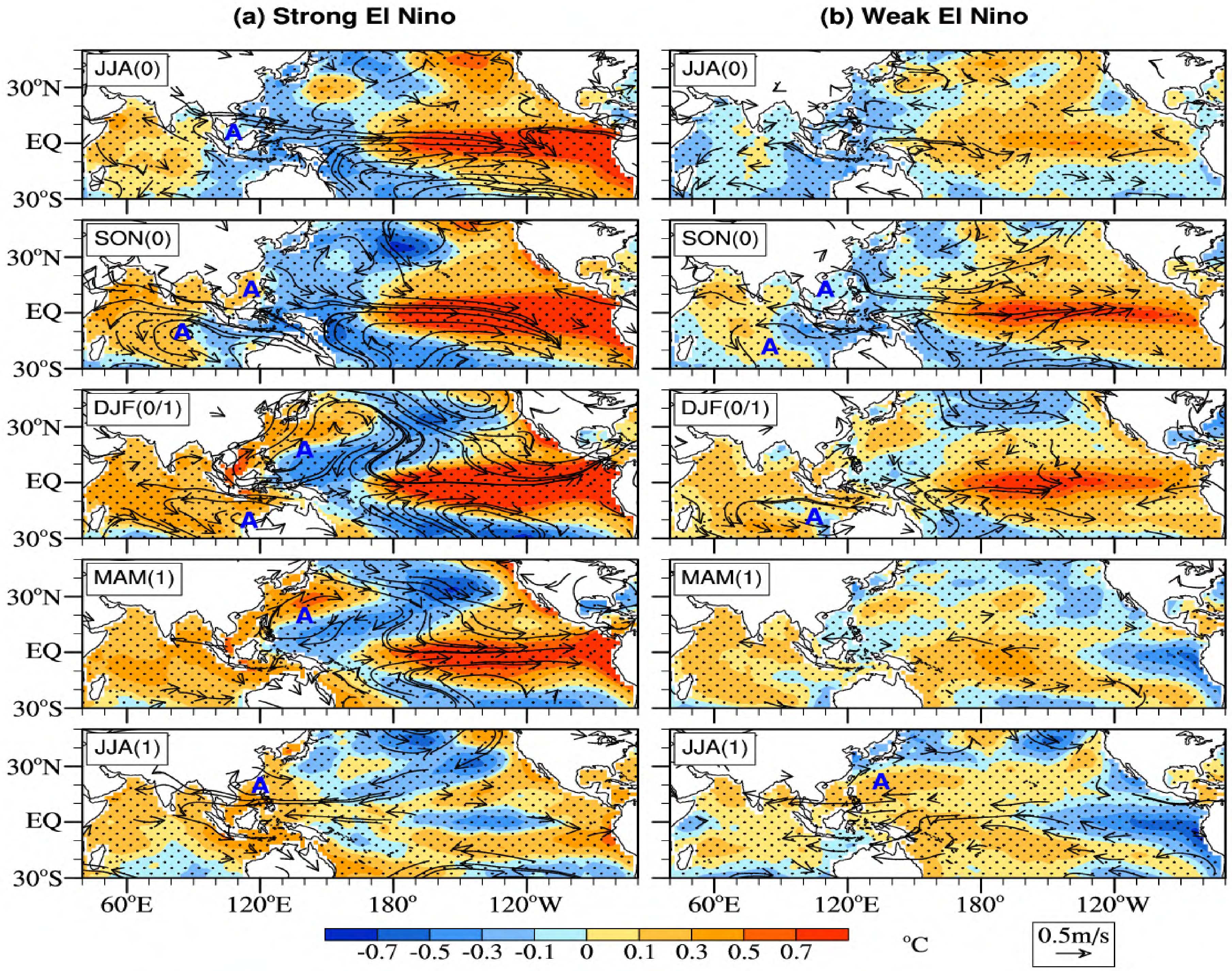
# Coupling mechanism between WPAC and Indo-Pacific SST dipole




Wang et al. (2013): WPSH - Indo-Pacific SST dipole coupled mode.
Xie et al. (2016): Indo-Pacific capacitor




However, during post-weak El Niño events, WPAC also emerges which enhances rainfall in the Yangtze River Valley.
Why?




During weak El Niño events, the E Pacific warming ends earlier

By JJA(1) the eastern Pacific SST evolves into a cold phase

The WPAC re-emerges during the summer JJA(1) as a forced response to the eastern Pacific cooling.

# Summary

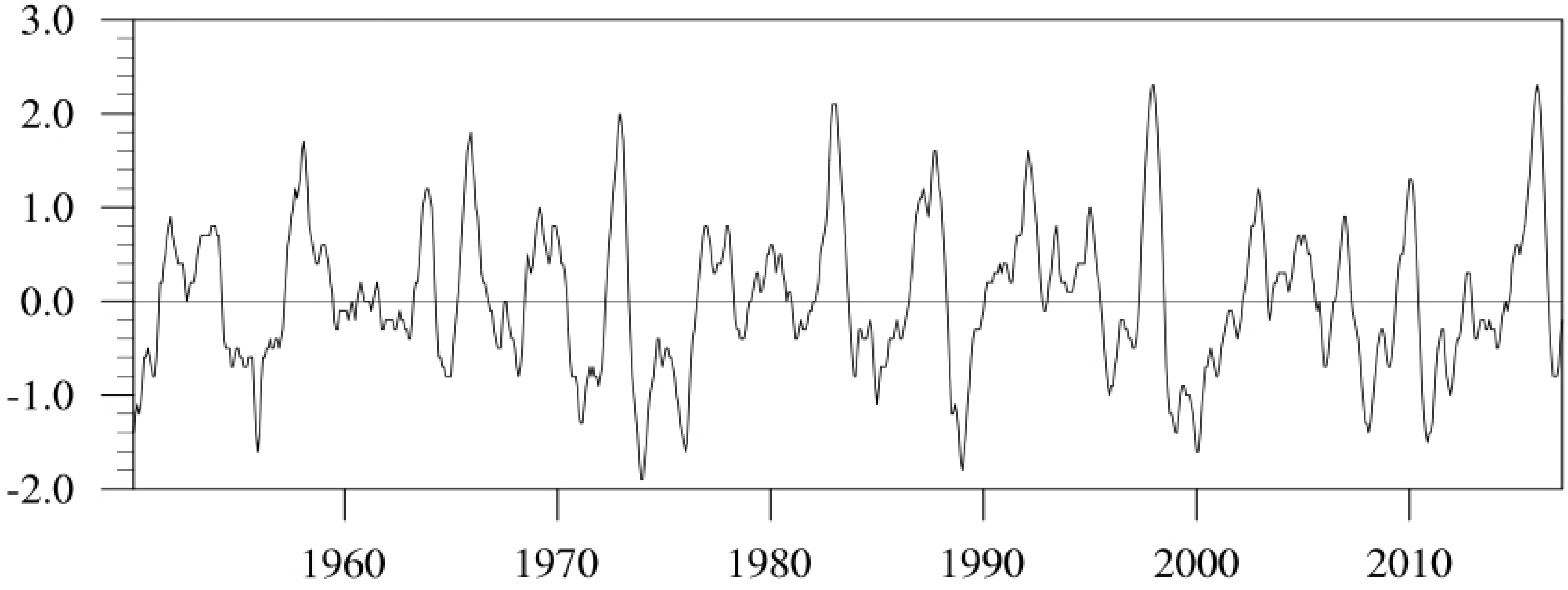
(1) Over EA, the spatial patterns of the rainfall anomalies response to all El Nino are generally variable.
(2) The robust  signal to all El Nino events is the deficient rainfall in northern China during the El Niño developing summer. In addition, strong El Niño persuasively enhances rainfall along EA subtropical front zone from DJF(0/) to MAM(1).
(3) The precipitation response strongly depends on the integrated intensity and the evolution of El Nino. Strong and weak El Nino affect post-El Nino summer rainfall through different physical processes.
(4) Only strong El Nino can excite monsoon-ocean interaction and prolong El Nino impact on EASM in JJA(1). During a weak El Niño the WPAC is a forced response to the eastern Pacific rapid cooling.

# Remarks

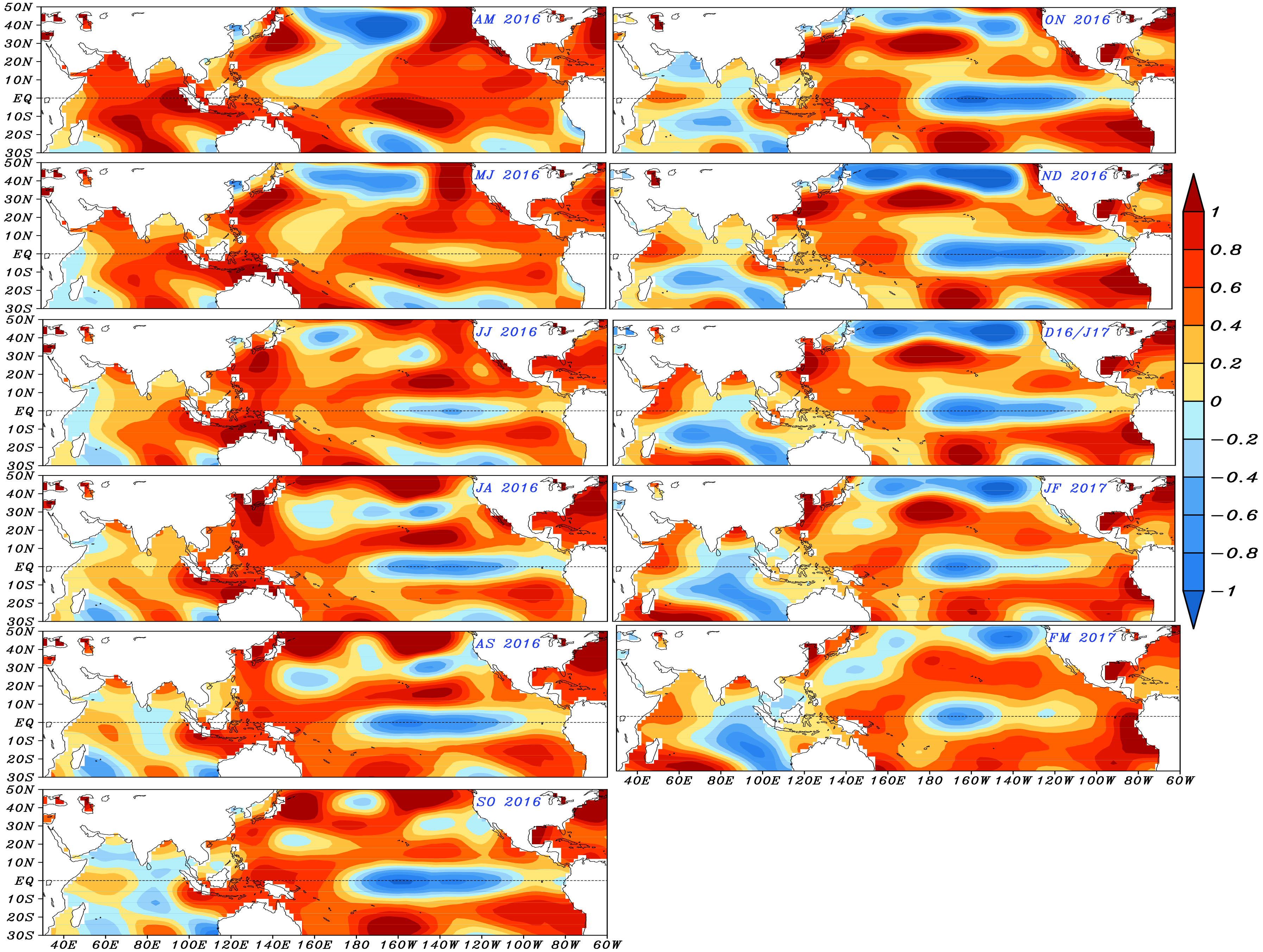
- Over East Asia (EA), JJA mean anomalies has a limited value in representing hydrological hazards.
- The traditional way of prediction of JJA mean precipitation anomalies may not be adequate over EA.
- The fundamental drivers of the A-A monsoon variability: ENSO induced indirect teleconnection, monsoon-ocean interaction, and regulation of monsoon annual cycle.

# What about EA precipitation in summer of 2017?

# ONI index (1950-2017)



# SSTA bimonthly running mean (AM 2016 —— FM 2017)

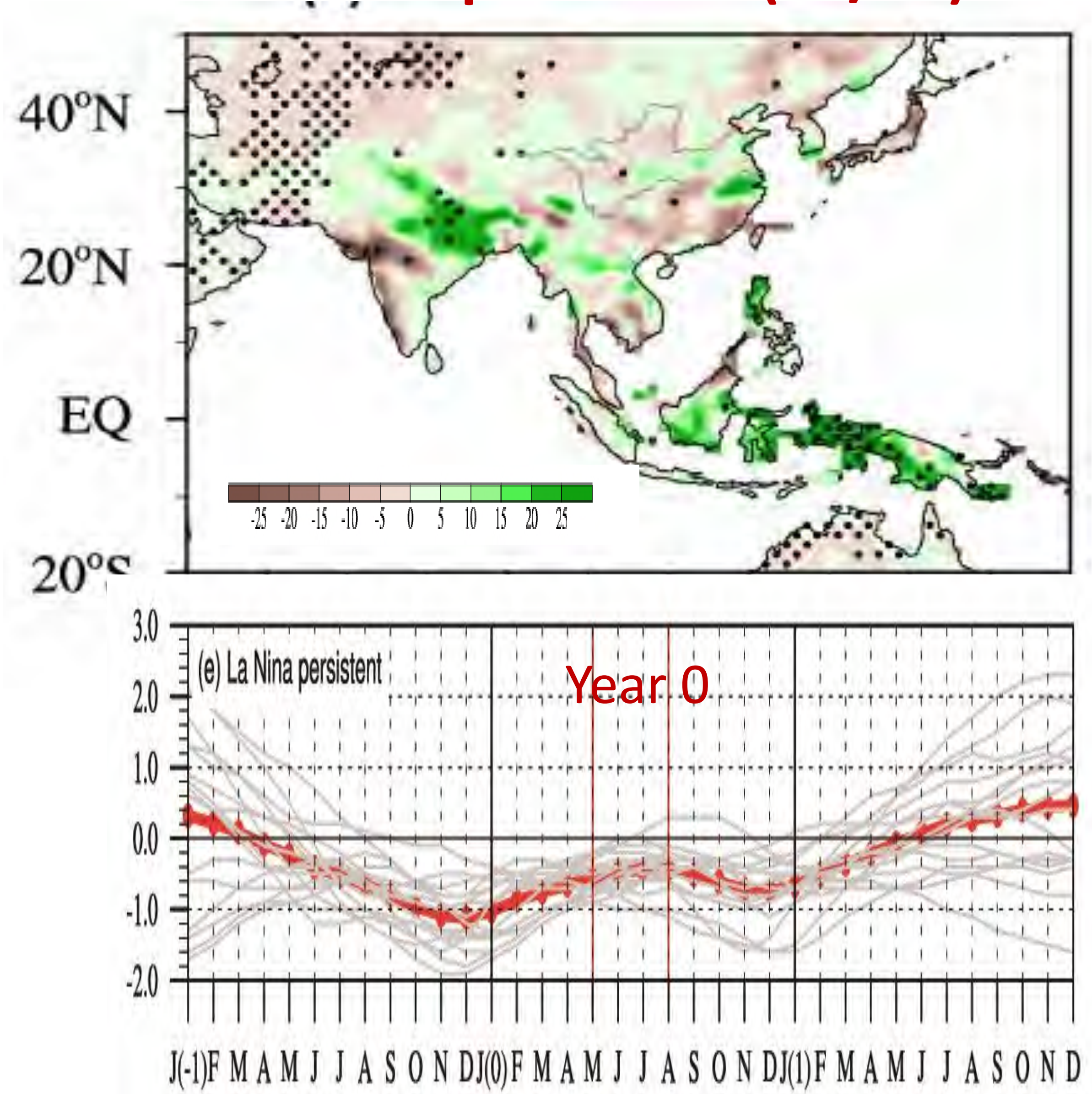


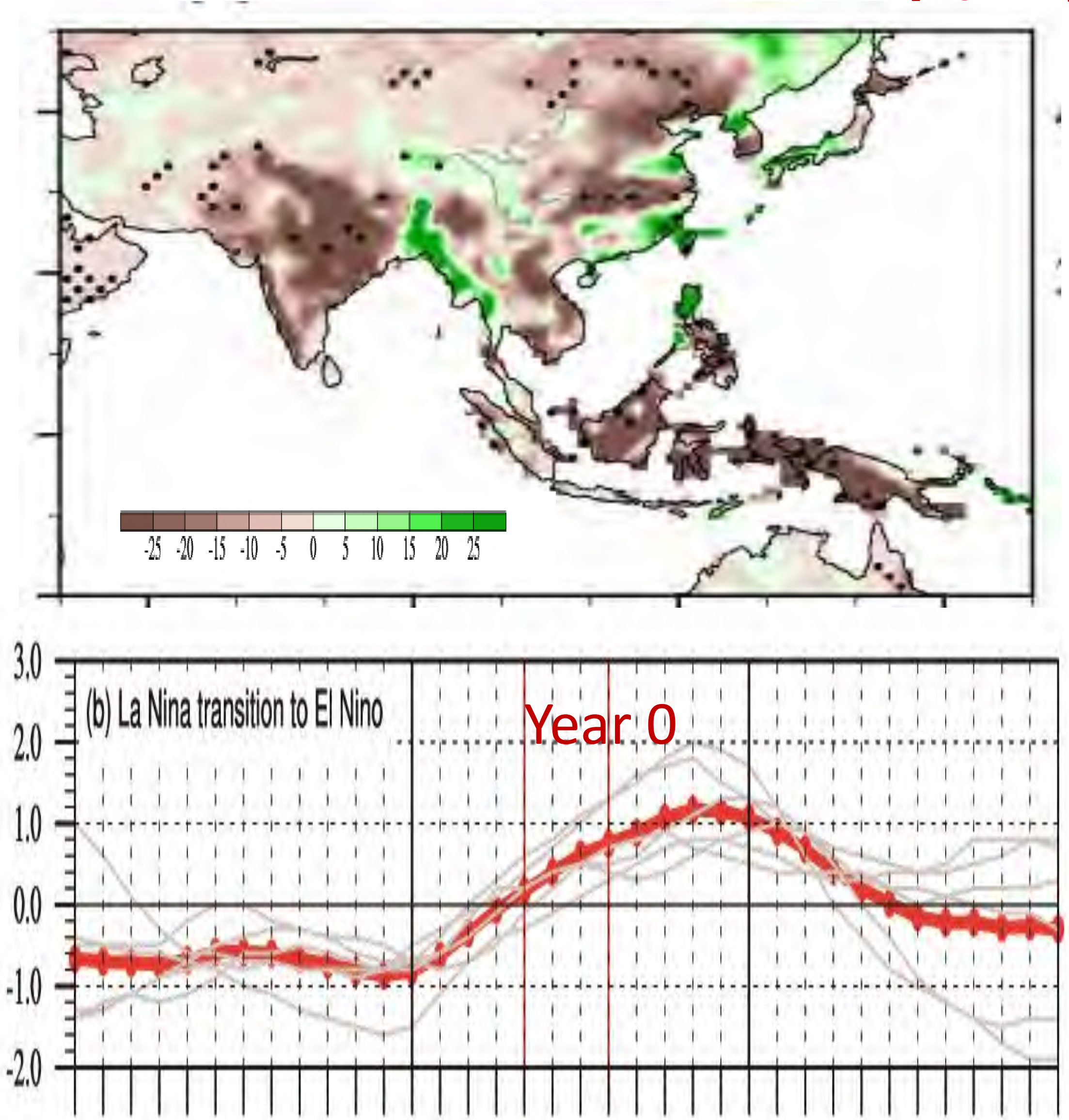

DATA:ERSST V4 (2016.Apr-2017 Mar)
Climate period: 1979-2017

# Given the evolution of 2015-16 El Nino-La Nina, two possible scenarios

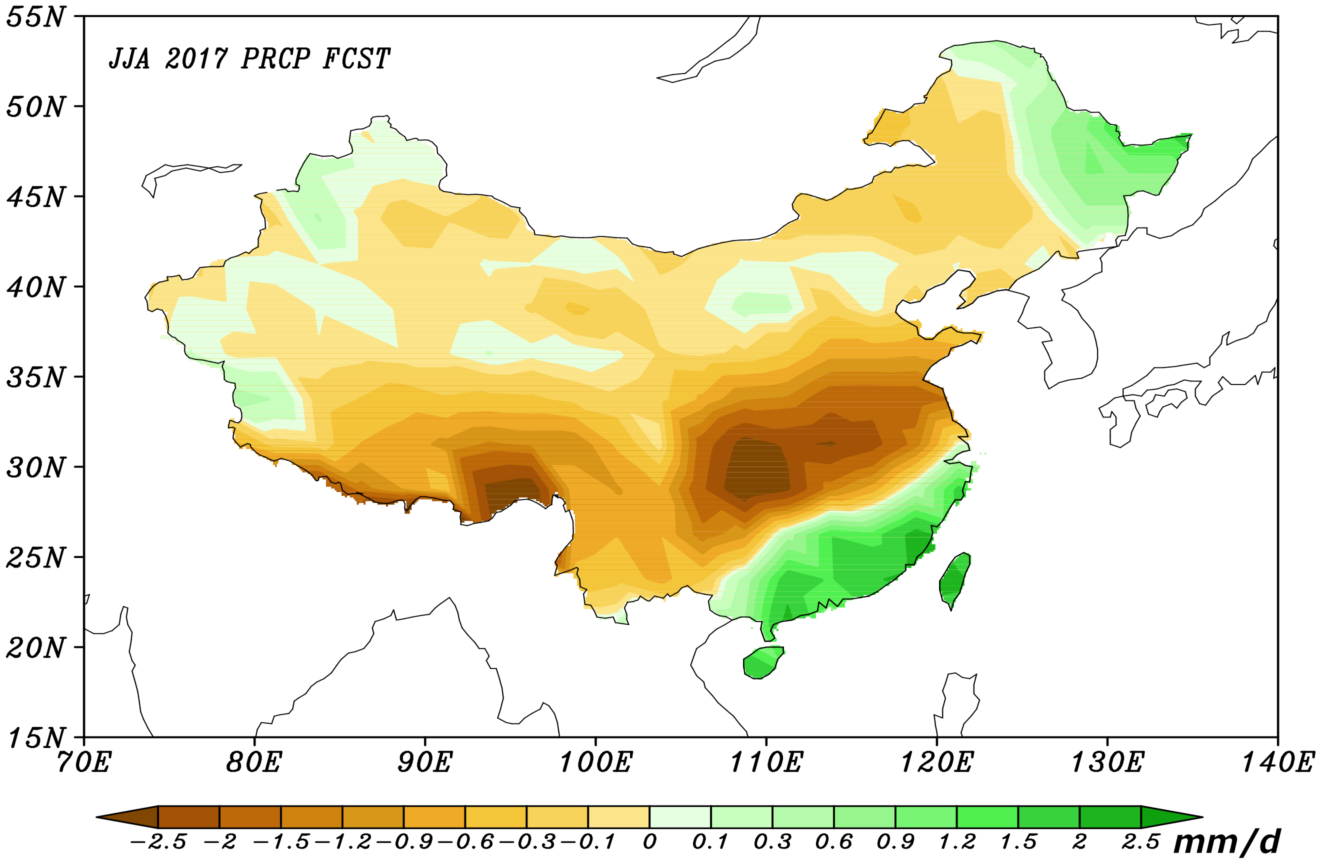
## La Nina persistent (16/22)

## La Nina Transition to El Nino (6/22)



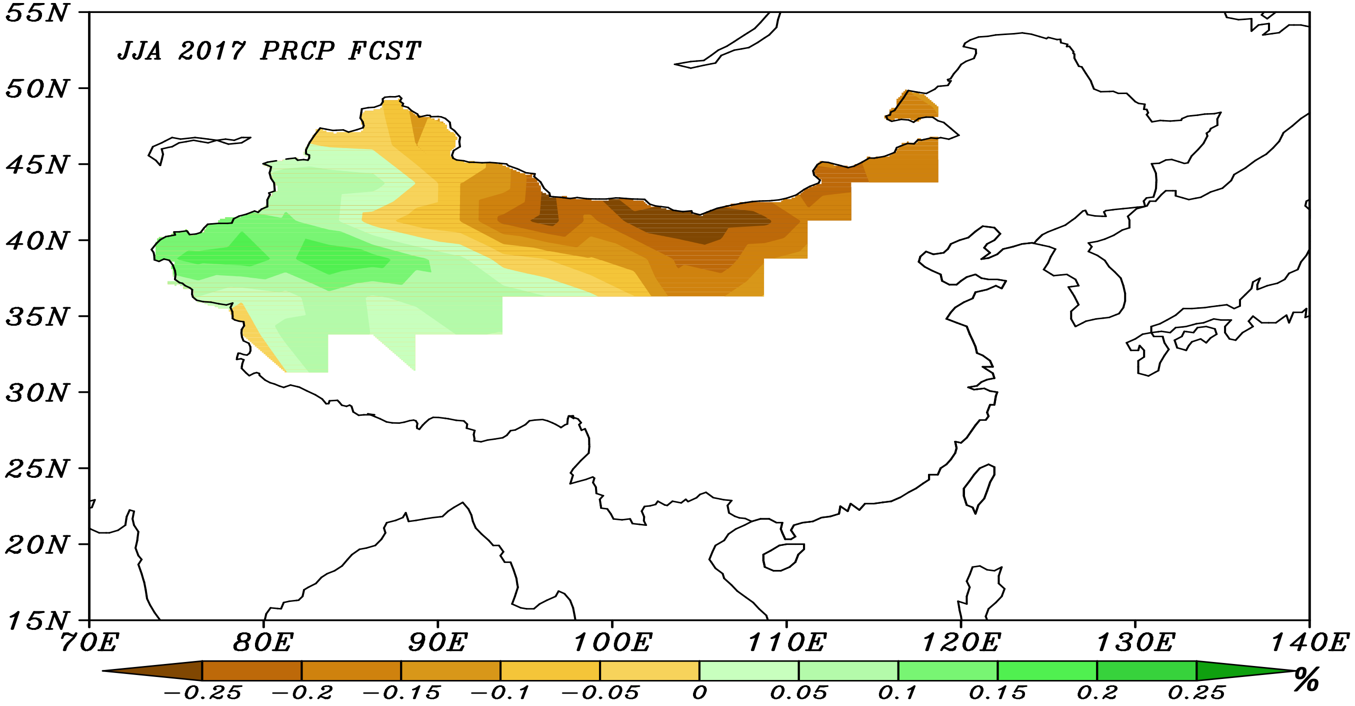



# Predicted rainfall anomaly pattern of JJA 2017 over CN



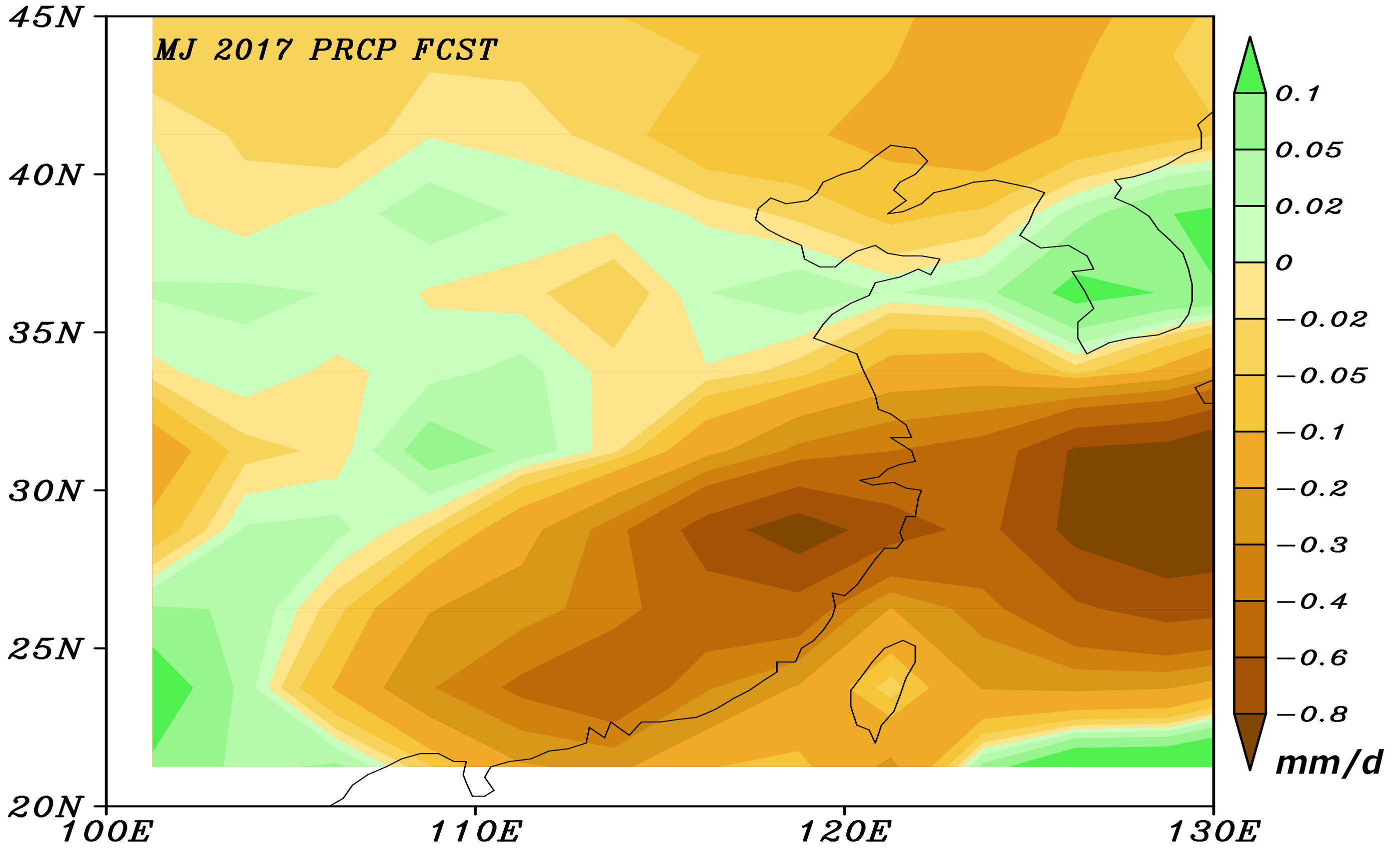

- **Predictor field:** DJ SST/T2m
- **Ref.:** Wen Xing, Bin Wang, So-Young Yim, 2016: Long-Lead Seasonal Prediction of China Summer Rainfall Using an **EOF-PLS** Regression-Based Methodology, Journal of Climate, 2016, 29(5): 1783–1796.

# Predicted Percentage Rainfall Anomaly pattern in JJA 2017 over NW China




- **Method: PMA** Predictable Mode Analysis (first 2 modes)
- **Predictor fields:** FMA/A-minus-FM SST/T2m
- **Ref.** Wen Xing, Bin Wang, 2016: Predictability and prediction of summer rainfall in the arid and semi-arid regions of China, Climate Dynamics, DOI: 10.1007/s00382-016-3351-9.

# Predicted rainfall anomaly pattern of MJ 2017 over EA




- **Method:** PMA (first 3 modes) Predictable Mode Analysis
- **Predictor fields:** JFMA/MA-minus-JF SST/T2m/SLP
- **Ref.** Wen Xing, Bin Wang, So-Young Yim, and K.-J. Ha, 2017: Predictable patterns of the May–June rainfall anomaly over East Asia, J. Geophys. Res. Atmos., 122, doi:10.1002/2016JD025856.

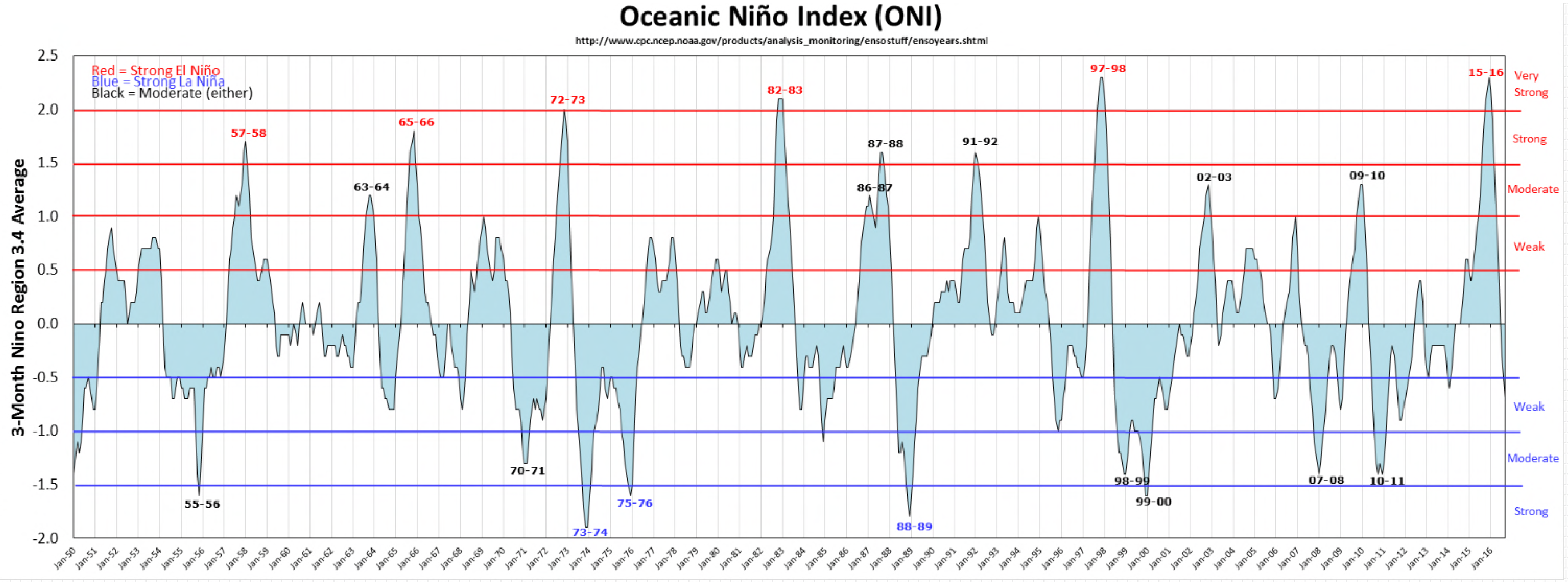
# Other two works

1. Wen Xing · Bin Wang · So-Young Yim, 2014:
“Peak-summer East Asian rainfall predictability and prediction part I: Southeast Asia” . Climate Dynamics.
2. So-Young Yim · Bin Wang · Wen Xing, 2015:
“Peak-summer East Asian rainfall predictability and prediction part II: extratropical East Asia”, Climate Dynamics,


Mahalo!
Any
comment?

# Data

- Precipitation: (a) Global Precipitation Climatology Project (GPCP, v2.3) dataset from 1- 1979 to 8- 2016, (b) Global land Precipitation Climatology Centre (GPCC) dataset (Schneider et al., 2014) from 1- 1957 to 8- 2016.
- Circulation: NCEP/NCAR Reanalysis I 1-1957 to 8-2016,
- SST: merged from HadISST (Rayner et al., 2003) and NOAA ERSST V4 (Huang et al., 2015) from 1- 1957 to 12- 2016.
- Significance tests for composites: (a) the composite mean (“signal”) is greater than 2SD of the spreading member events (“noise”). (b) Sign tests.



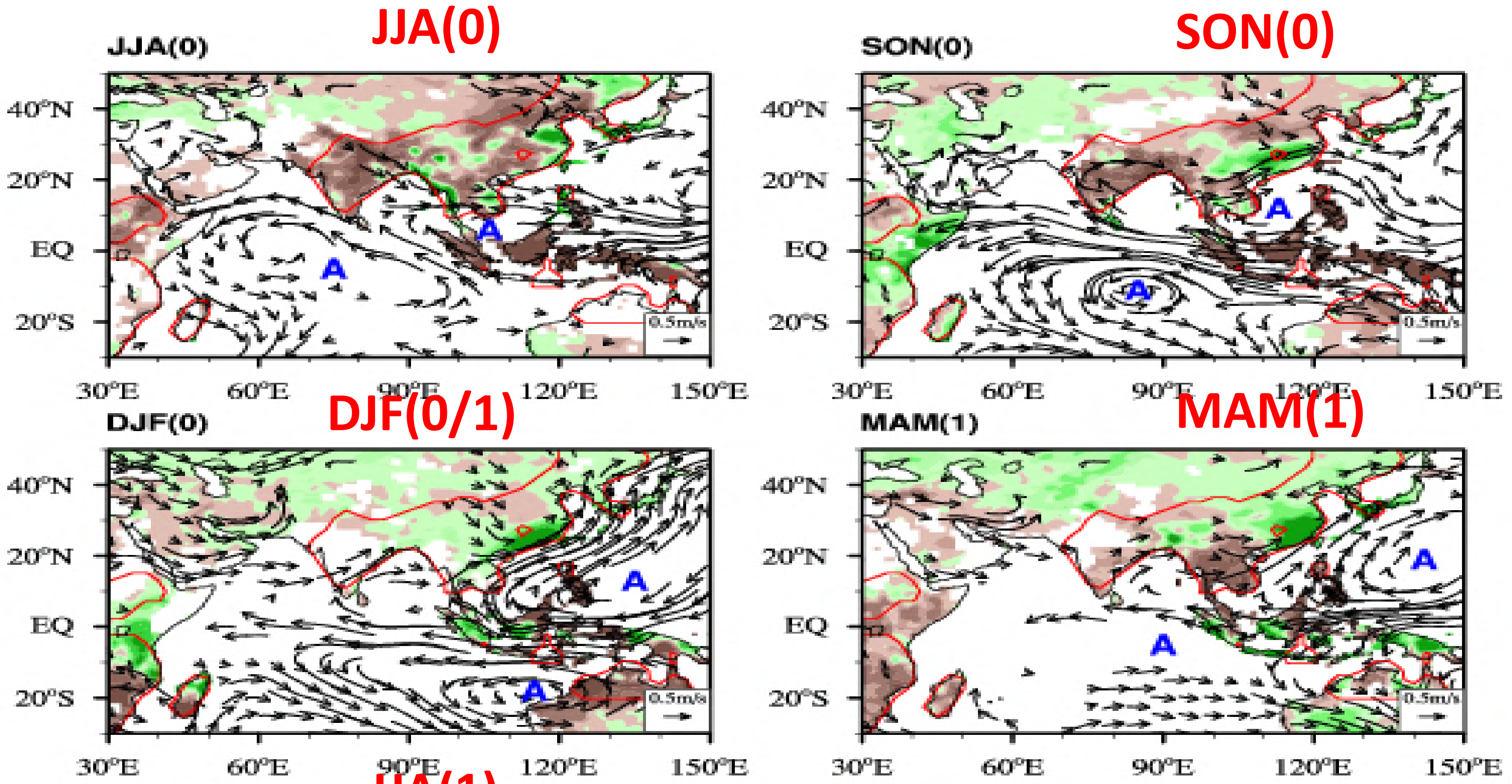

Super: 82,97,15

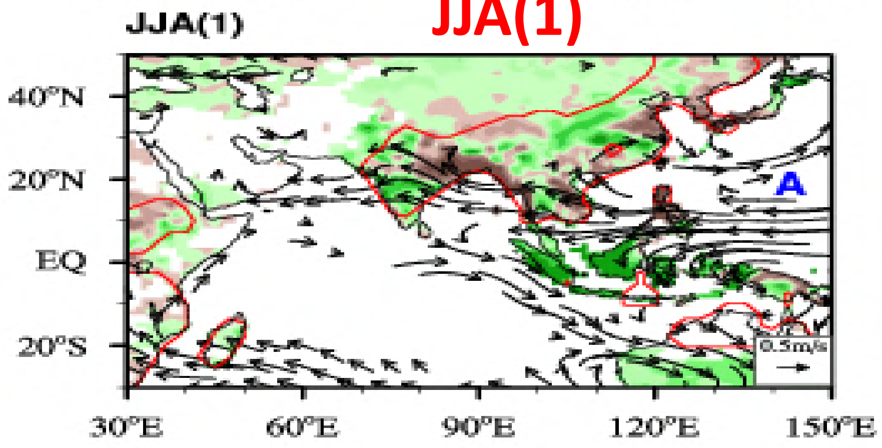
Strong: 57, 65,72, 87, 91,

Moderate: 63,86, 02, 09

Weak (9) (51,53),68, 69, 76, 77, 94,04,06.

From: http://ggweather.com/enso/oni.htm



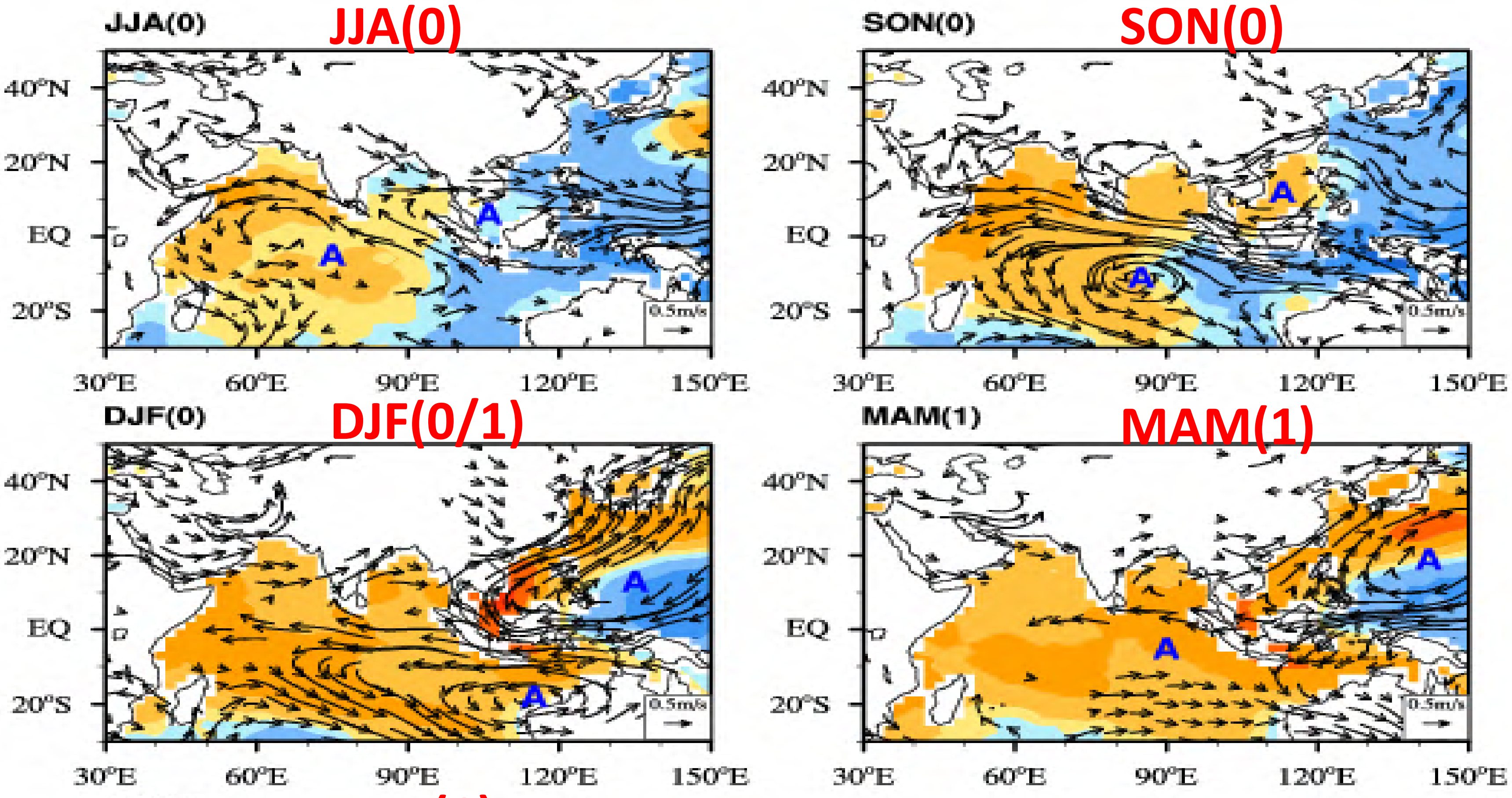



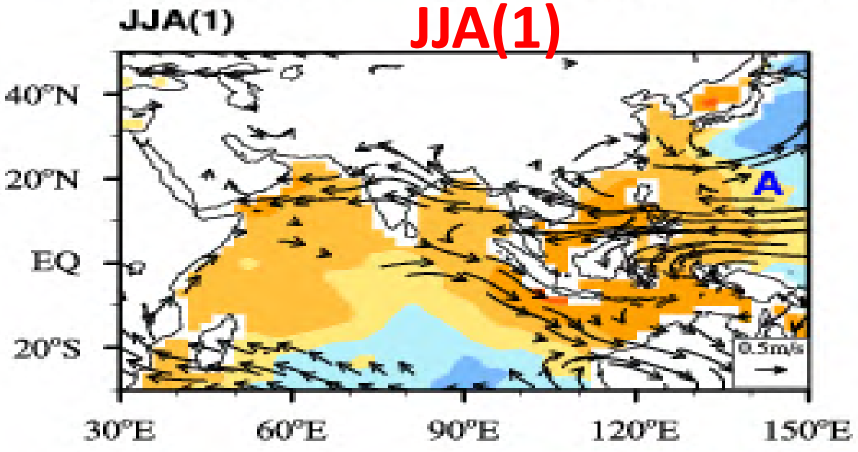


The WPAC anomaly occurs during the SON(0), further develops and expands eastward during DJF(0/1) and MAM(1), and weakens but maintains to JJA(1).

Composite **precipitation/850 winds** anomalies for **8 strong El Nino** (1957-2016)

Wang and Zhang 2002





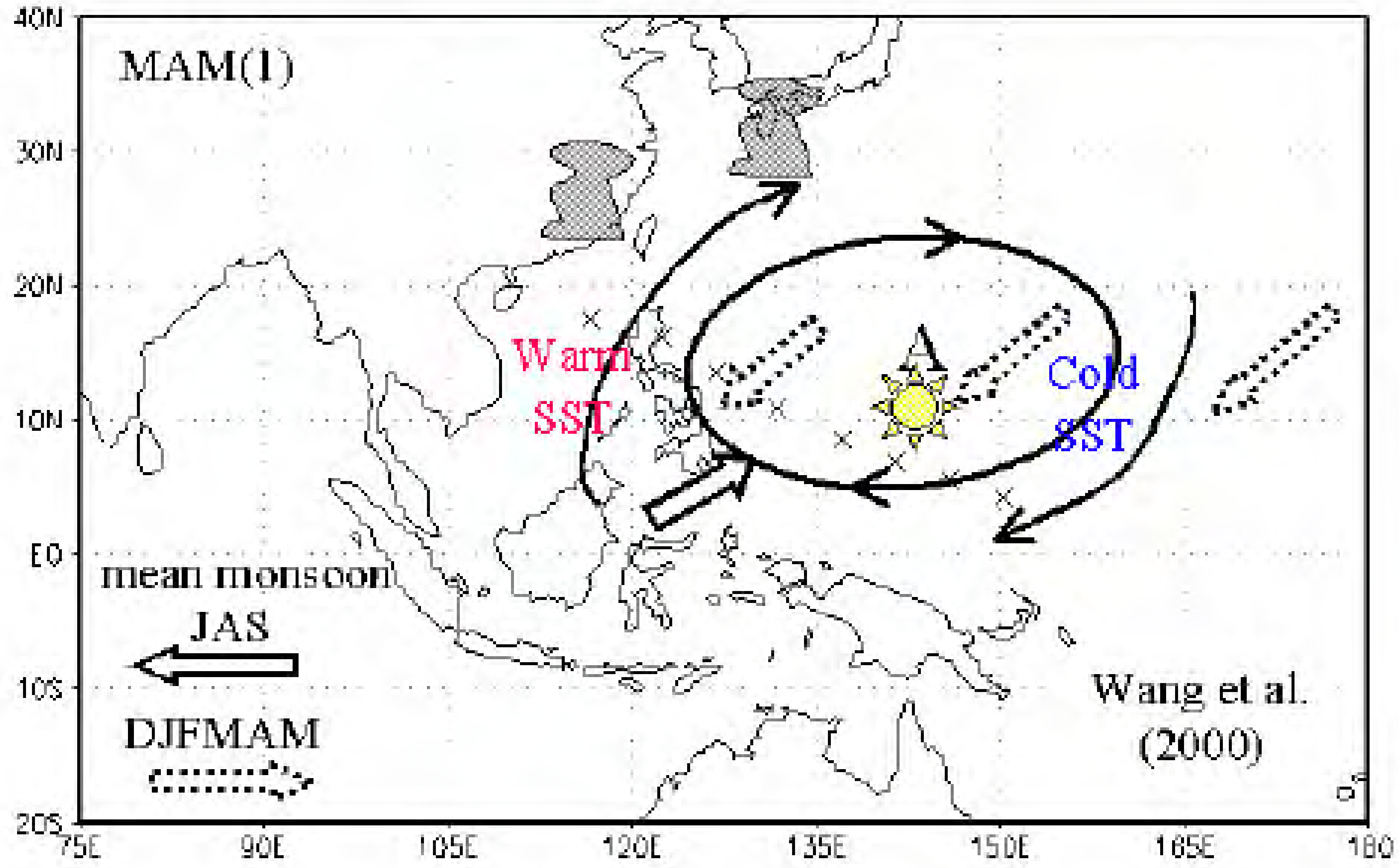
Composite **SST/850 winds** anomalies for **8 strong El Nino** (1957-2016)

- WNP AC is coupled with a dipole SSTA in mature and decay phases, with cold to the E-SE and warm to the W-NW of the AC center.

- SIO AC couples with IOD from JJA(0) to SON(0), but IOD disappears in DJF(0/1).

Wang et al. 2003

# EA response during an decaying phase of strong El Nino

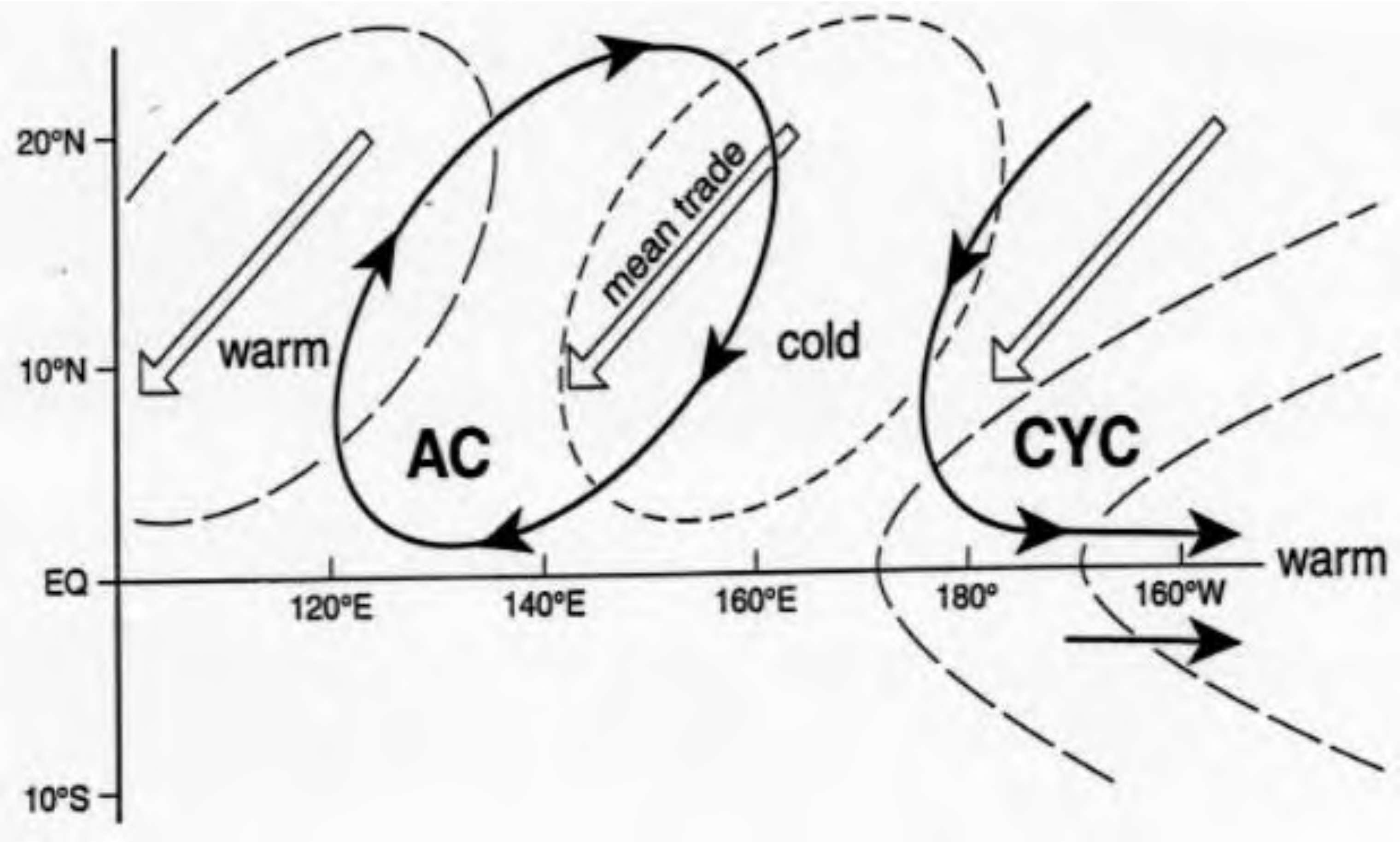



Monsoon-ocean interaction in the WNP maintain WP AC anomalies, which provides a bridge for "delayed" impact of El Nino to EASM.

WNP Subtropical High and Indo-Pacific SST coupled Mode

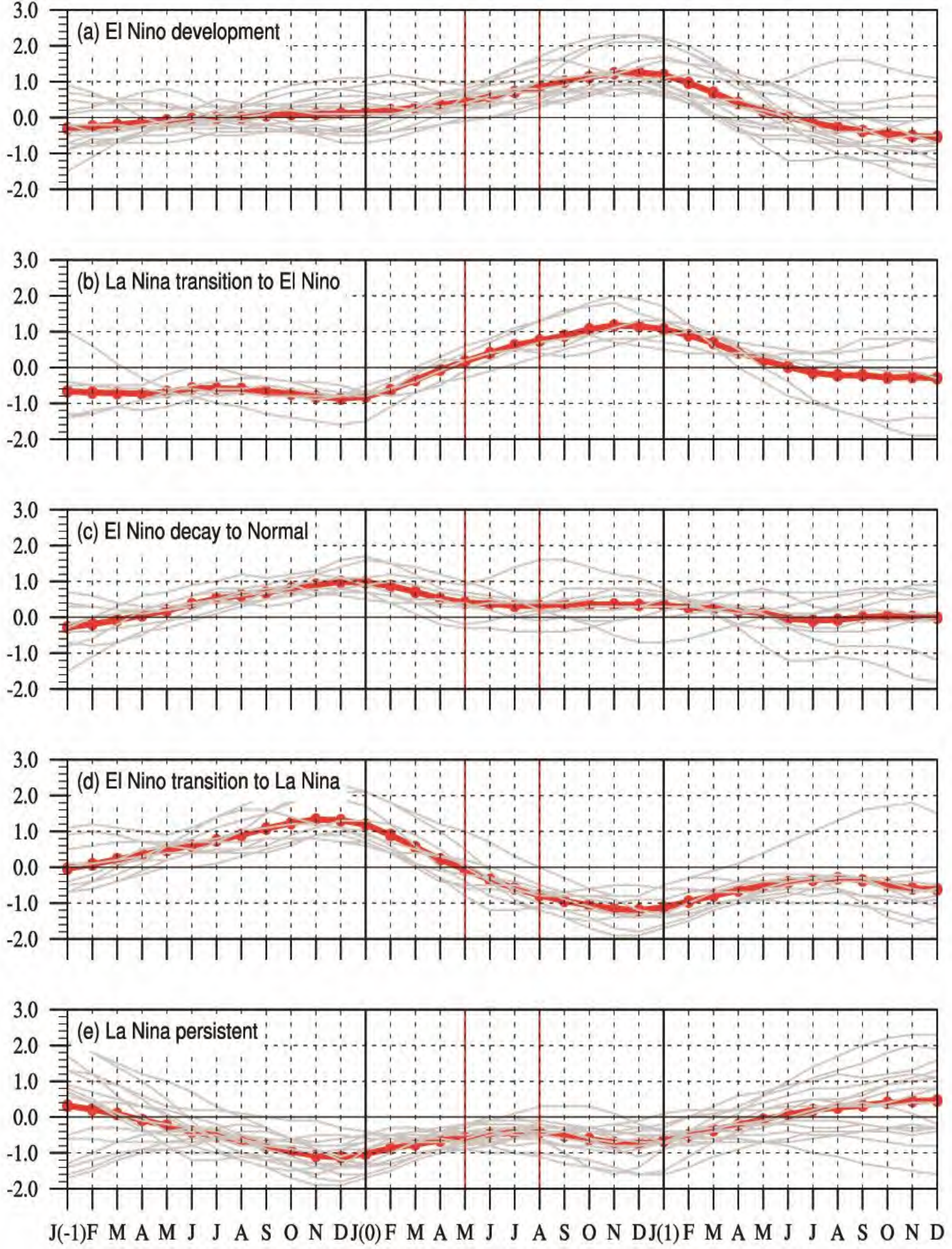
# Off-equatorial Rossby wave-SST feedback

## Maintains the WNP anticyclonic anomaly




(Wang, Wu, Fu 2000, JC)

Five categories of composite ONI index (1951-2016): year -1, 0, +1




**) El Nino development from Normal** (1953, 1957, 1963, 1969, 1977, 1982, 1986, 1987, 1991, 1994, 1997, 2002, 2004, 2006, 2015, 15 years),

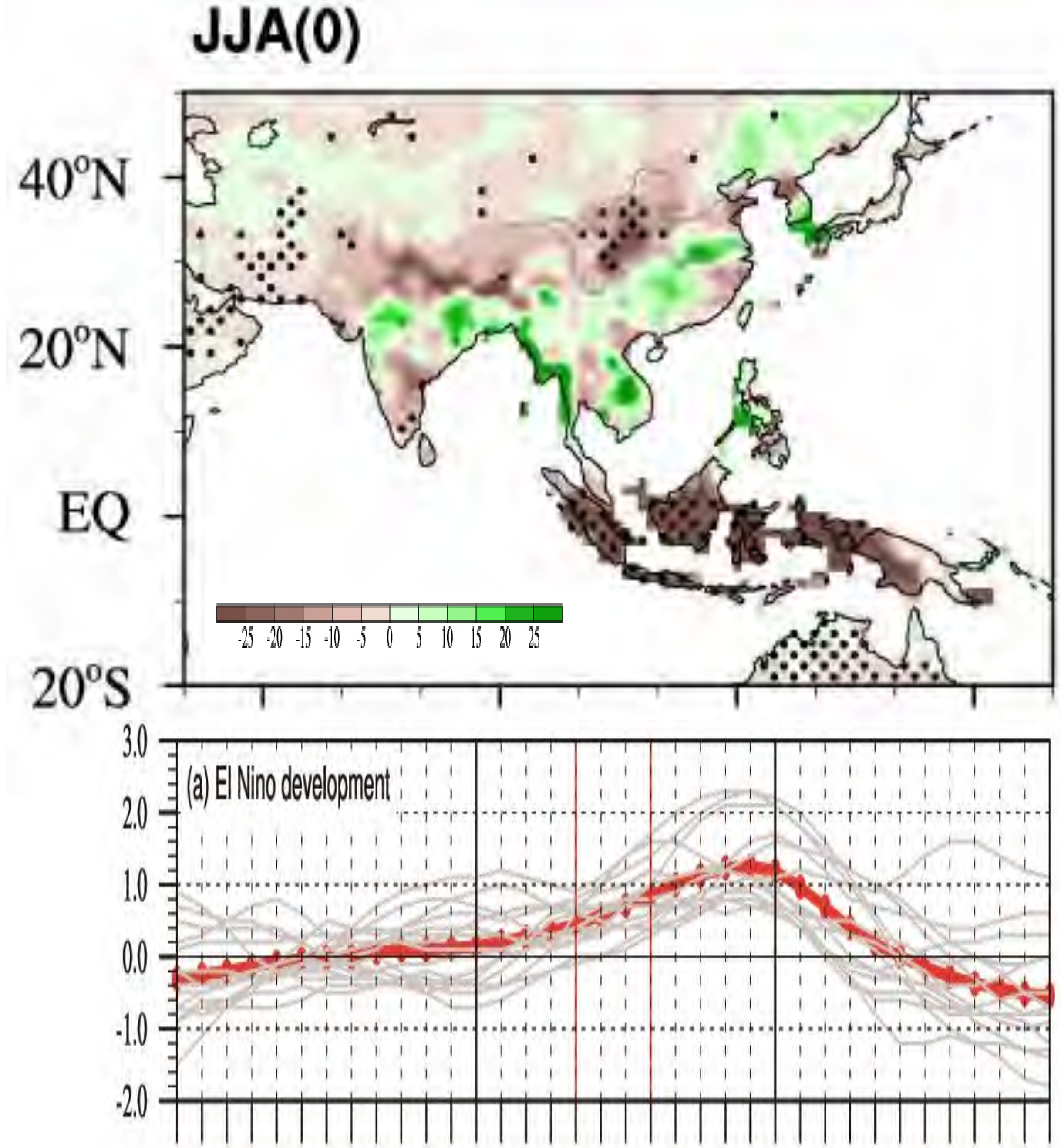
**) El Nino develops from La Nina transition** (1951, 1965, 1968, 1972, 1976, 2009, together 6 years),

**) El Nino decay to Normal** (1952, 1958, 1969, 1977, 1978, 1987, 1992, 2003, 2005, 9 years),

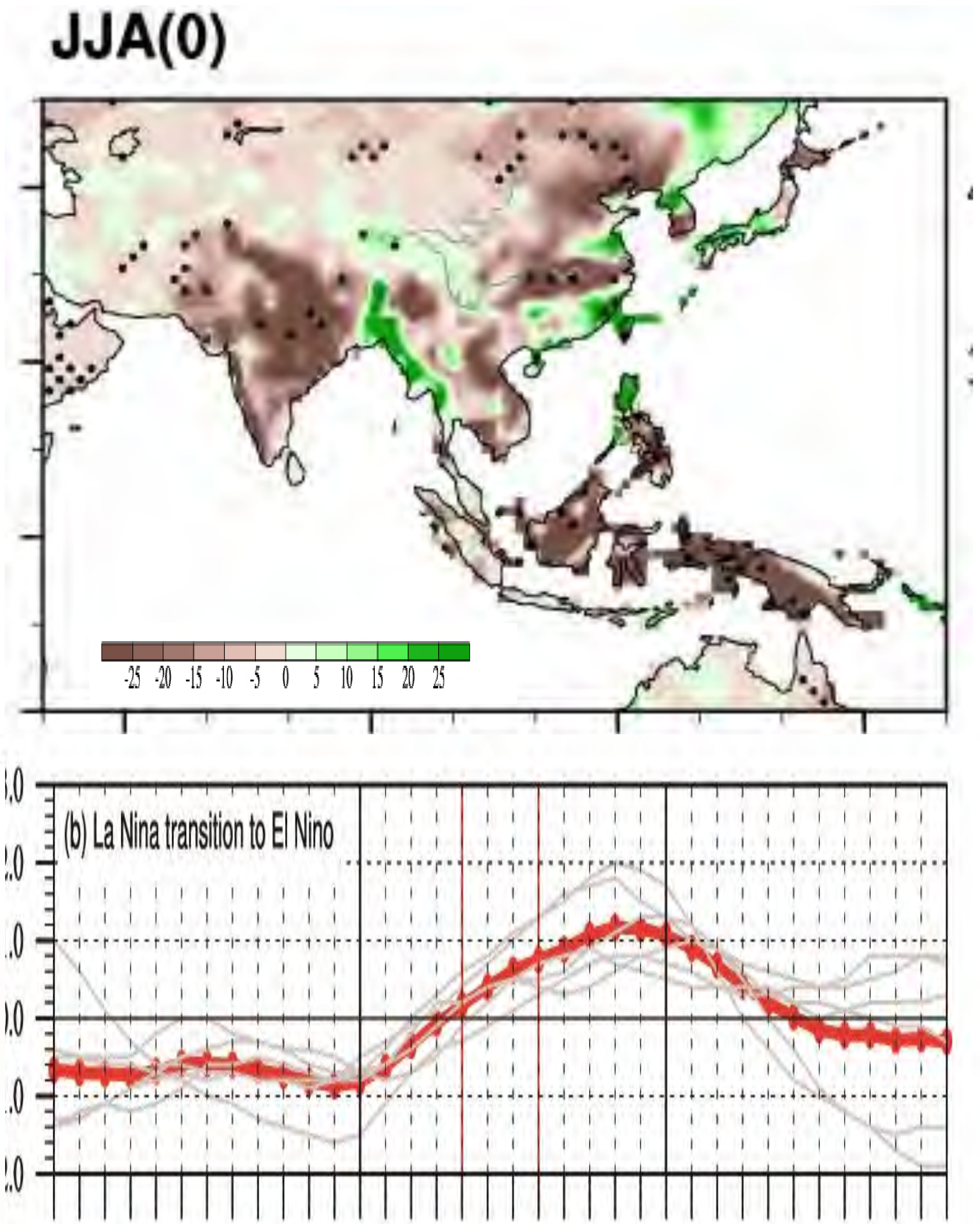
**) El Nino transition to La Nina** (1954, 1964, 1970, 1973, 1983, 1988, 1995, 1998, 2007, 2010, together 10 years)

**) La Nina persistent years** (1955, 1956, 1967, 1971, 1974, 1975, 1984, 1985, 1989, 1996, 1999, 2000, 2001, 2008, 2011, 2012, together 16 years).

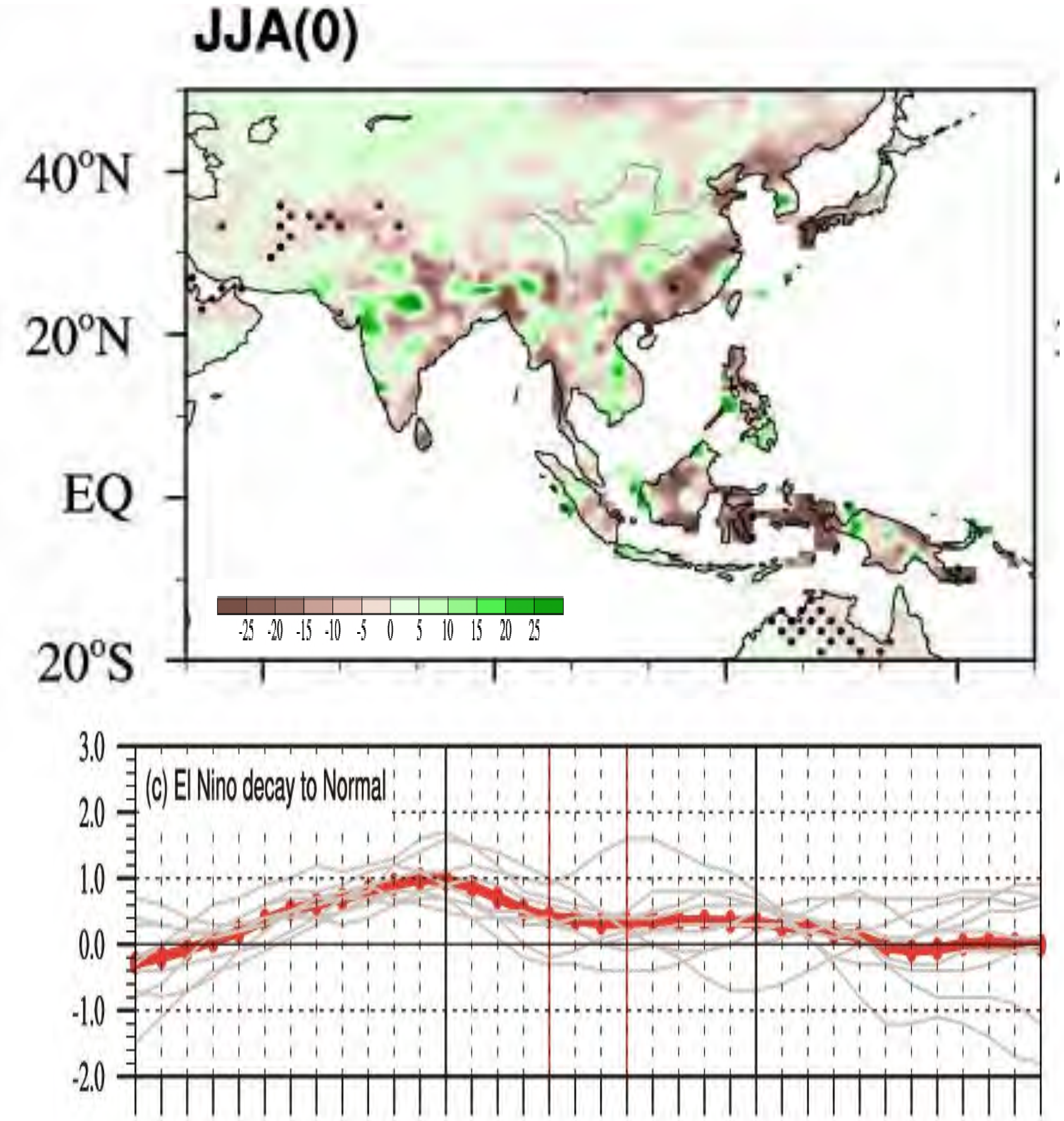
El Nino developing from Normal: 15 events.



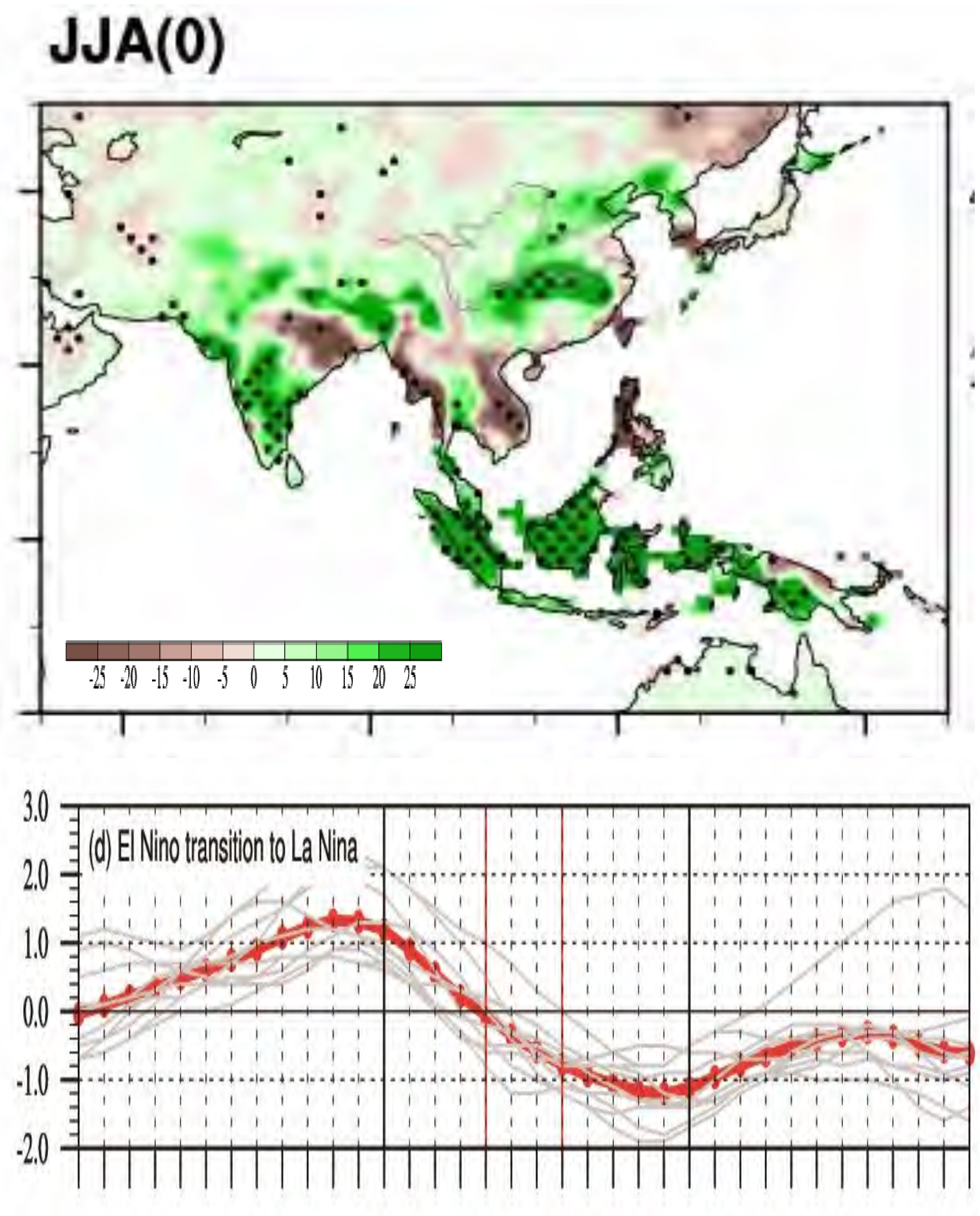

El Nino develops from El Nino: 6 events

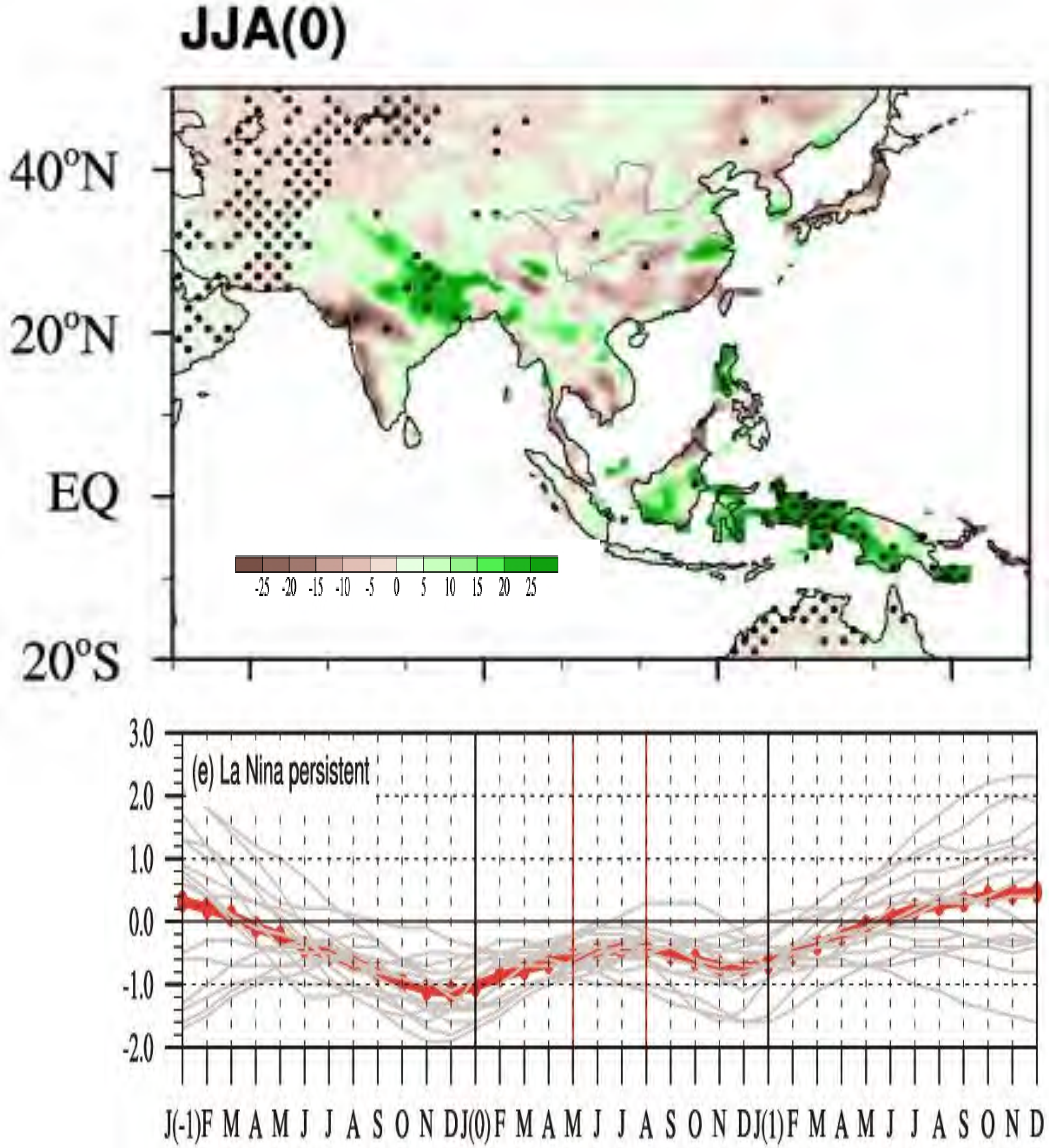


**El Nino Decay to Normal or El Nino**: 10 events




**El Nino transition to a La Nina**: 11 events:






La Nina persistent years: 16 events: 55, 56, **67**, 71, 74, **75**, 84, 85, 89, 96, 99, 00, 01, 08, 11,12 (16 summers)

Composite precipitation anomalies (mm/mon). Dotted areas indicate the composite anomalies are significant at 95% confidence level (num>=12).

**Oceanic Niño Index (ONI)** Website:
http://www.cpc.ncep.noaa.gov/products/analysis_monitoring/ensostuff/ensoyears.shtml

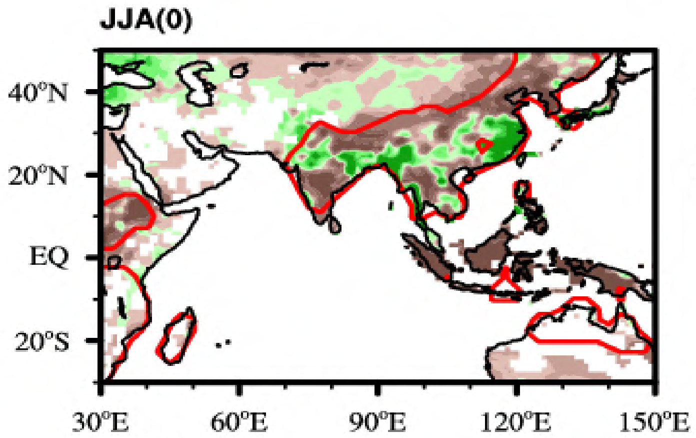
| Year | DJF | JFM | FMA | MAM | AMJ | MJJ | JJA | JAS | ASO | SON | OND | NDJ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 2010 | 1.3 | 1.2 | 0.9 | 0.5 | 0.0 | -0.4 | -0.9 | -1.2 | -1.4 | -1.5 | -1.4 | -1.4 |
| 2011 | -1.3 | -1.0 | -0.7 | -0.5 | -0.4 | -0.3 | -0.3 | -0.6 | -0.8 | -0.9 | -1.0 | -0.9 |
| 2012 | -0.7 | -0.5 | -0.4 | -0.4 | -0.3 | -0.1 | 0.1 | 0.3 | 0.3 | 0.3 | 0.1 | -0.2 |
| 2013 | -0.4 | -0.4 | -0.3 | -0.2 | -0.2 | -0.2 | -0.3 | -0.3 | -0.2 | -0.3 | -0.3 | -0.3 |
| 2014 | -0.5 | -0.5 | -0.4 | -0.2 | -0.1 | 0.0 | -0.1 | 0.0 | 0.1 | 0.4 | 0.5 | 0.6 |
| 2015 | 0.6 | 0.5 | 0.6 | 0.7 | 0.8 | 1.0 | 1.2 | 1.4 | 1.7 | 2.0 | 2.2 | 2.3 |
| 2016 | 2.2 | 2.0 | 1.6 | 1.1 | 0.6 | 0.1 | -0.3 | -0.6 | -0.8 | -0.8 | -0.8 | -0.7 |
| 2017 | -0.4 | -0.2 | | | | | | | | | | |

DESCRIPTION from the website: Warm (red) and cold (blue) periods based on a threshold of +/- 0.5$^o$C for the ONI [3 month running mean of ERSST.v4 SST anomalies in the Niño 3.4 region (5$^o$N-5$^o$S, 120$^o$-170$^o$W)], based on centered 30-year base periods updated every 5 years.
For historical purposes, periods of below and above normal SSTs are colored in blue and red when the threshold is met for a minimum of 5 consecutive overlapping seasons.

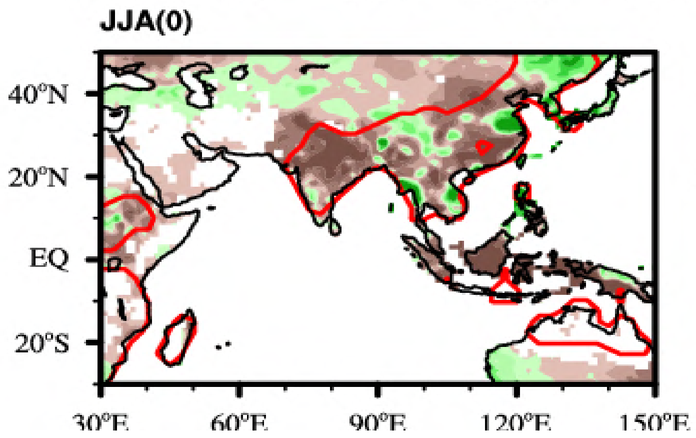
2016/2017 is a weak La Nina event based on its criterion.

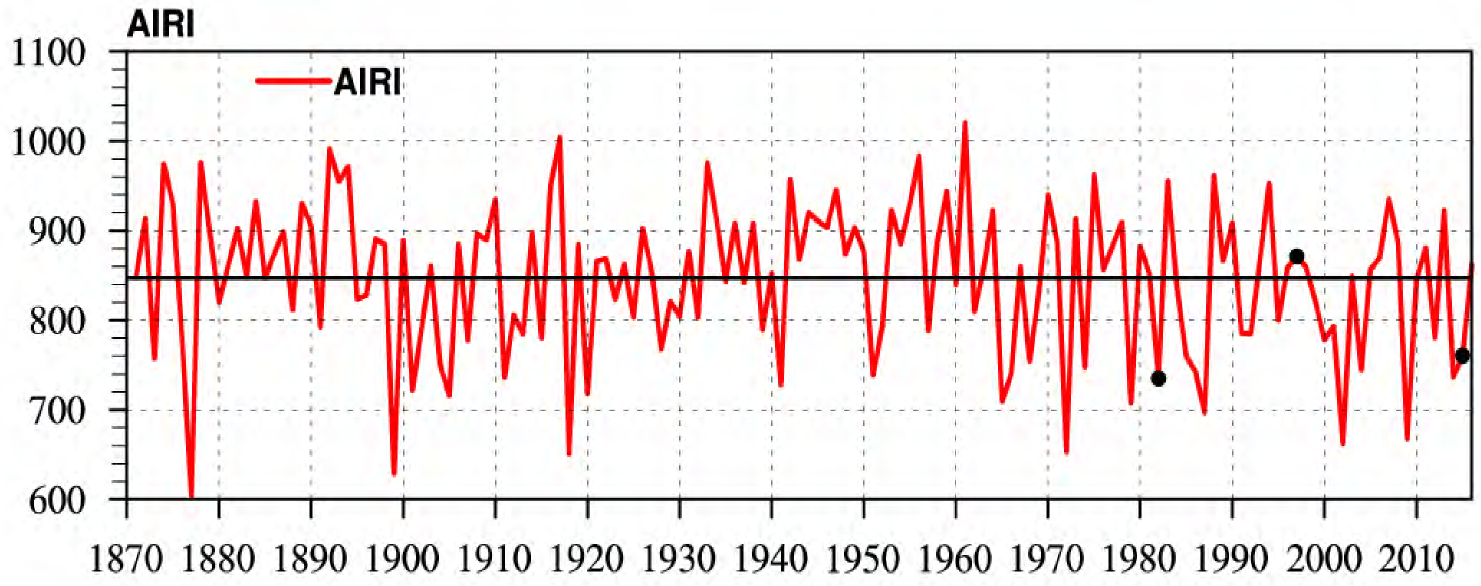
# Super El Nino does not necessarily cause super deficient ISM

3 super El Nino composite




5 strong El Nino composite

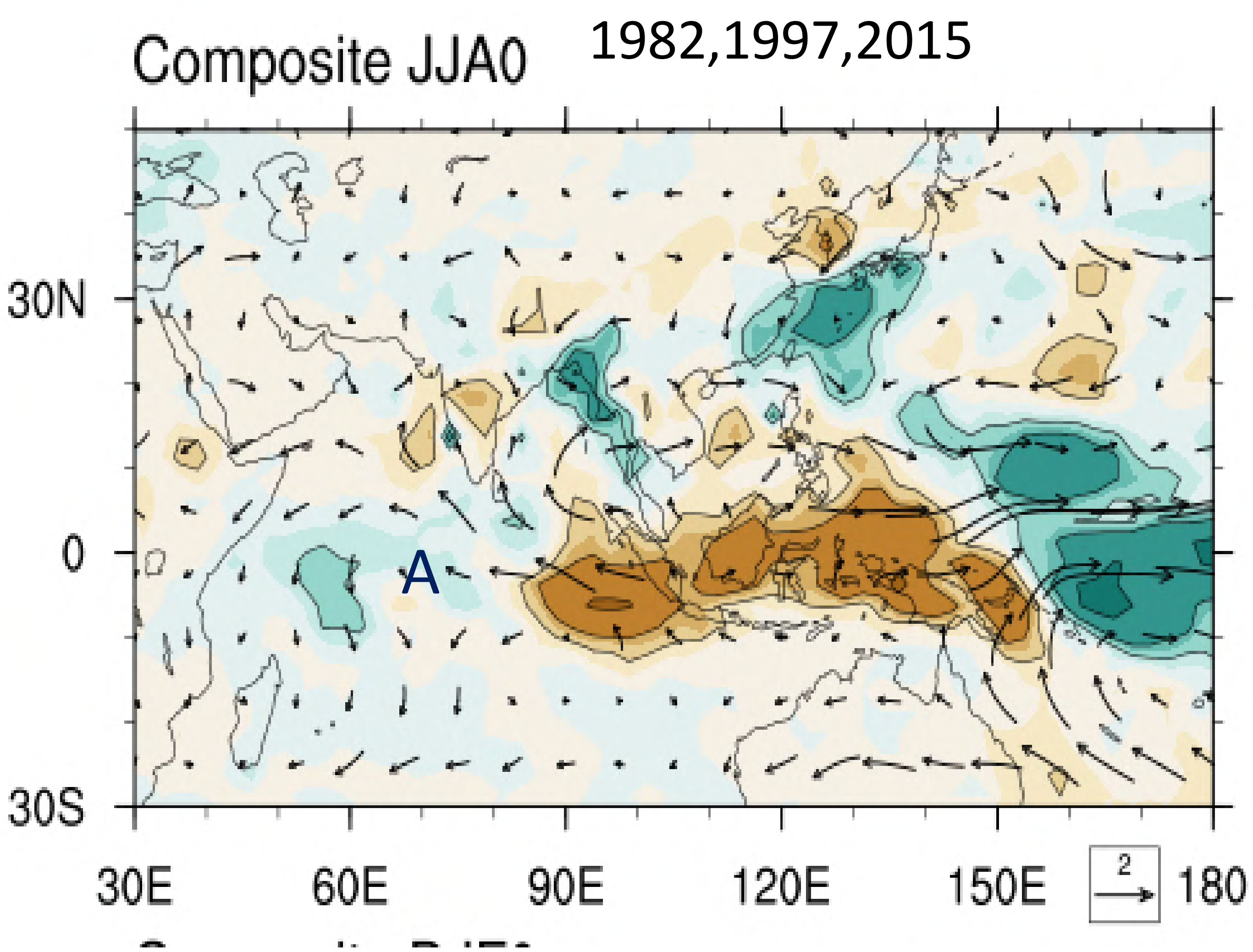



3 Super El Nino events do not cause terribly deficient ISM rainfall.

Supper and strong Ninos events show different impacts on ISM in JJA(0).

# Why super El Nino does not necessarily cause super deficient ISM




## Monsoon-ocean interaction in IO can offset El Nino 's impacts

--Equatorial Bjerkness positive feedback (IOD/IOZM) (Webster et al. 1999, Saji et al. 1999)

--Negative feedback by monsoon-induced anomalies (Meehl 1994, 1997, Lau and Nath 2000, Webster et al. 2002, Loschnigg et al. 2003).

--Off-equatorial Rossby Wave-SST feedback either positive or negative, depending on background annual cycle (Wang et al. 2003)

# What are the fundamental causes of the AAM interannual variability?

1) Remote El Nino/La Nina forcing is a primary factor, but not a full story.

2) Local monsoon-warm ocean interaction is important:

anomalous WPSH – SST dipole feedback

3) Annual cycle plays important hidden roles:

a) controls the nature of the monsoon-ocean feedback

b) modifies the atmospheric response to remote El Niño forcing

# Motivation

The increased rainfall along the East Asia (EA) subtropical front from the El Niño developing to decaying summer is a robust signal of all three super El Niño events.

Many studies have documented the influence of the El Nino on EA rainfall (Fu and Li 1978, Wang and Zhao 1981, Guo 1987, Wang and Li 1990, Wu et al. 2004, Yuan and Yang 2012a, b).

Surprisingly, the El Niño impact over EA is absent on the canonical El Niño impact map.

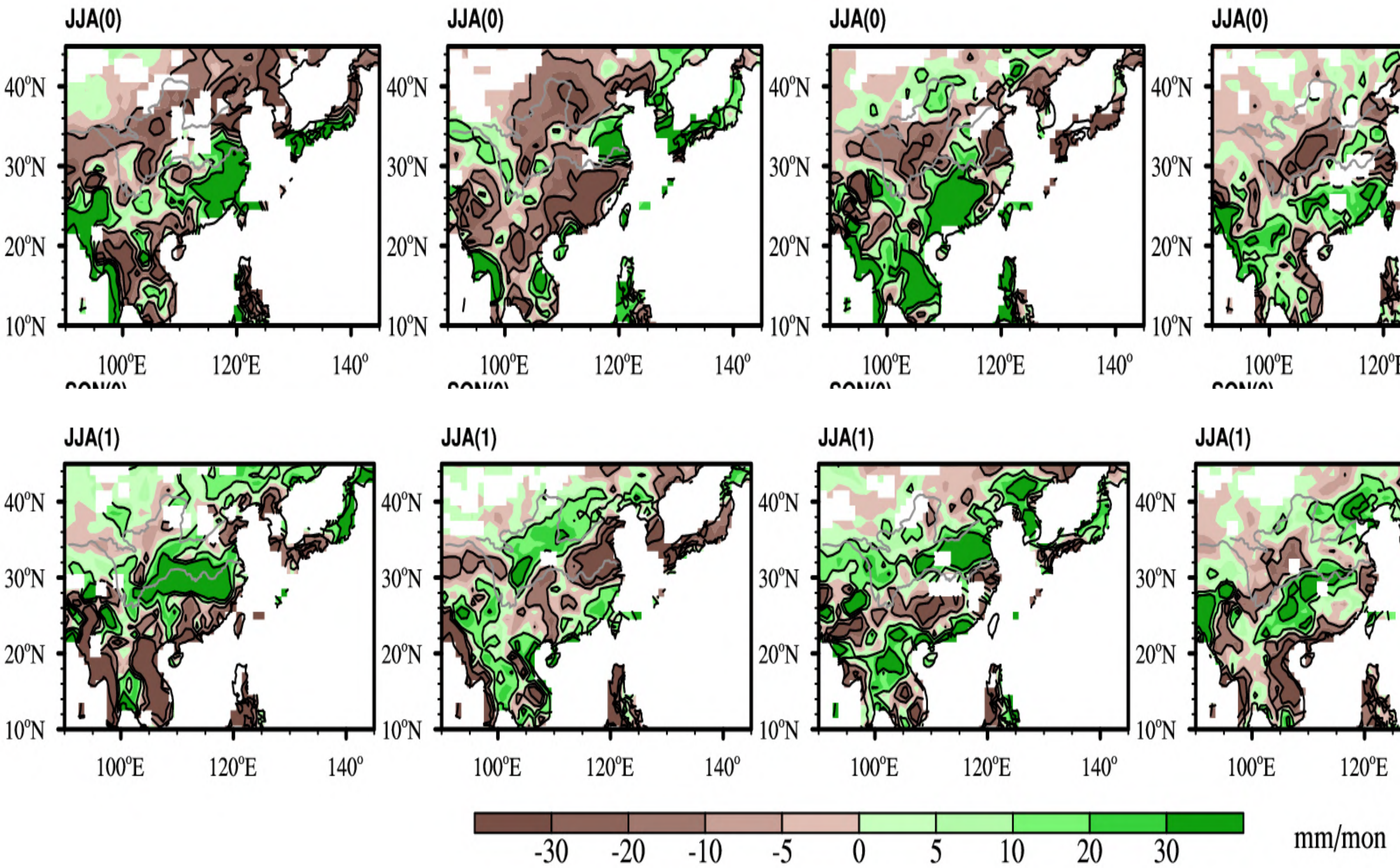
To comprehend this quandary, we compare impacts of the 2015 El Niño with those of the other 15 El Niño episodes over the past 60 years.

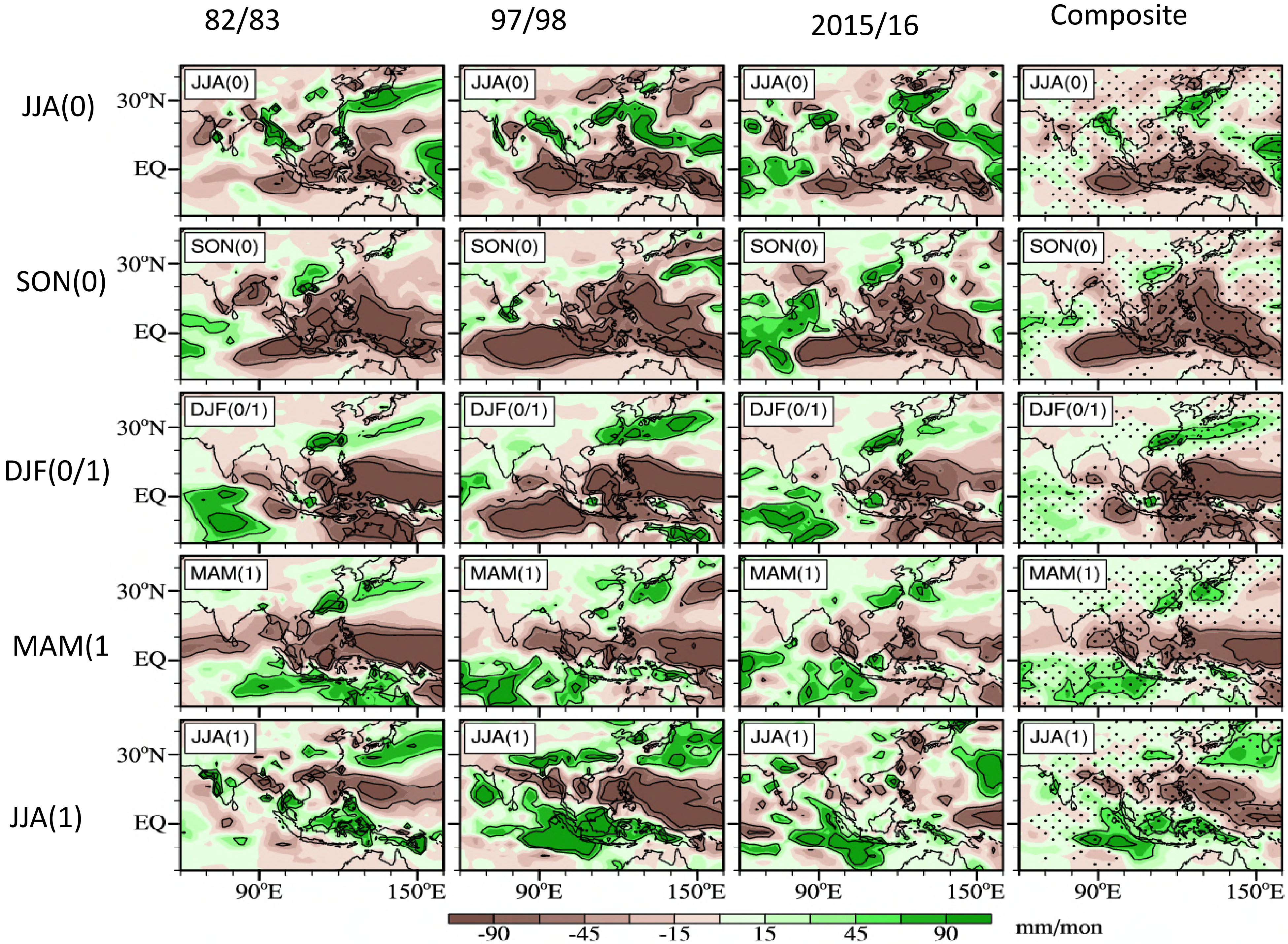
The notion of treating monsoon-warm ocean as a coupled system has been elaborated in many previous studies (Webster et al. 1999; Lau and Nath 2000; Wang et al. 2003).

The AMIP type of experiments cannot simulate the monsoon anomalies even given the strongest 1997-98 El Niño forcing (Wang et al. 2004),

Over the summer monsoon regions the SST is generally a passive response to atmosphere rather than a forcing (Wang et al. 2005). Therefore, the effect of the Indian Ocean warming should be demonstrated by numerical experiments with coupled models as properly done by Lau et al. 2005; Chowdary et al. 2010; Wang et al. 2013 and Xiang et al. 2013.

# Why are the El Niño impacts on EA summer monsoon rainfall so variable?





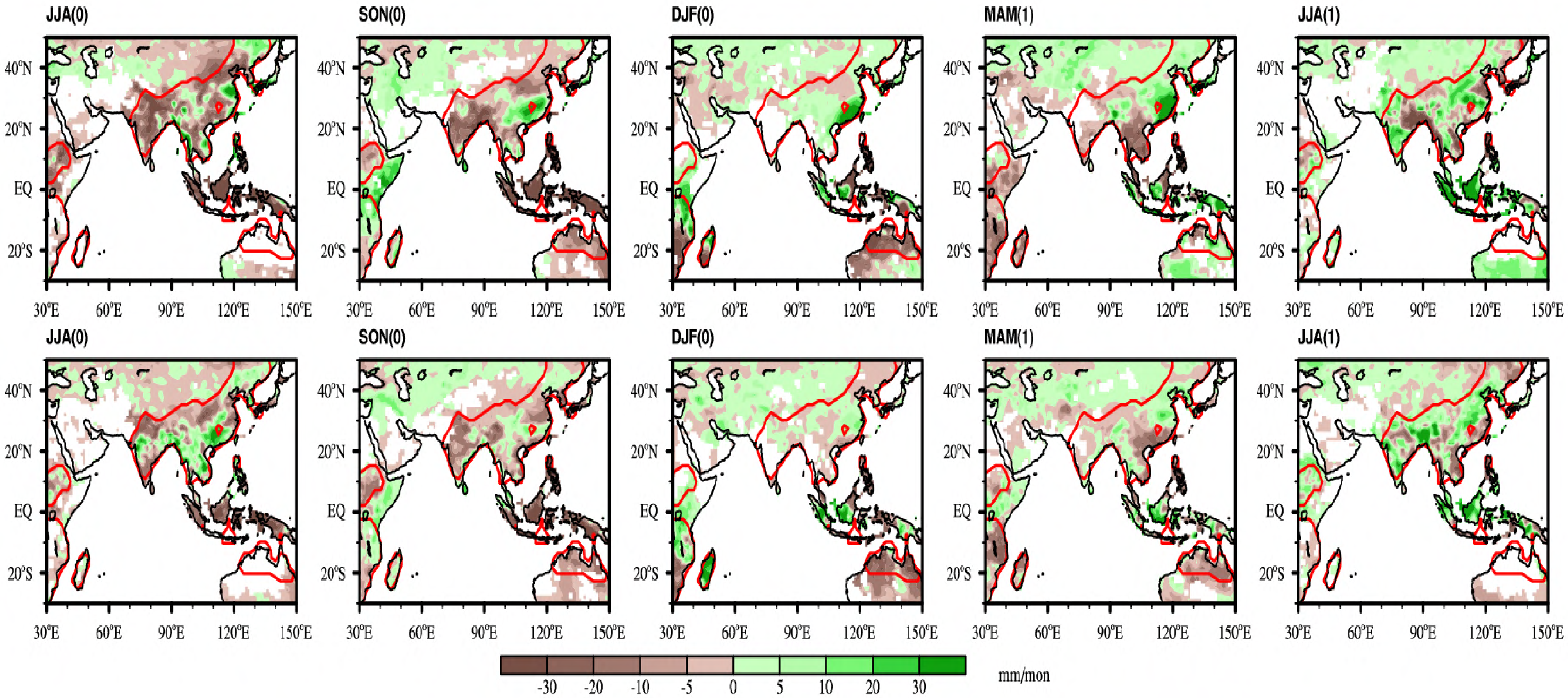

Considerable similarities, especially Maritime continent and Philippine Sea

Over EA, Enhanced rainfall along the East Asia subtropical front from SON(0) to MAM(1). But signals in JJA(0) and JJA(1) are weak.

Are these features typical to other El Nino events?

The areas where signal is less than “noise” over land are are blocked. GPCP data are used.

# Why do the winter-spring wet anomalies in southern China occur only during the strong El Niño rather than during the weak El Niño?



# Science questions

- (a) why the El Niño impacts on EA summer monsoon (EASM) rainfall are so variable as seen from the JJA mean anomalies;
- (b) Under what conditions, the EA precipitation may have robust responses to El Niño-induced forcing?
- (c) why only strong El Niño events have robust increase of precipitation in southern China form SON(0) to MAM(1) and have a prolonged enhancement of EA subtropical frontal precipitation;
- (d) why the weak El Niño events also enhance rainfall in the Yangtze River Valley and northern China during the post-El Niño summer.

# Understanding ENSO impacts on AAM

1. Why do strong El Nino episodes have a delayed impact on EASM rainfall in JJA(1)?
2. Why supper El Nino does not necessity cause super deficient ISM in JJA(0)?
3. What are the fundamental causes of AAM interannual variability?

# What are the fundamental causes of the AAM interannual variability?

1) Remote El Nino/La Nina forcing is a primary factor, but not a full story.

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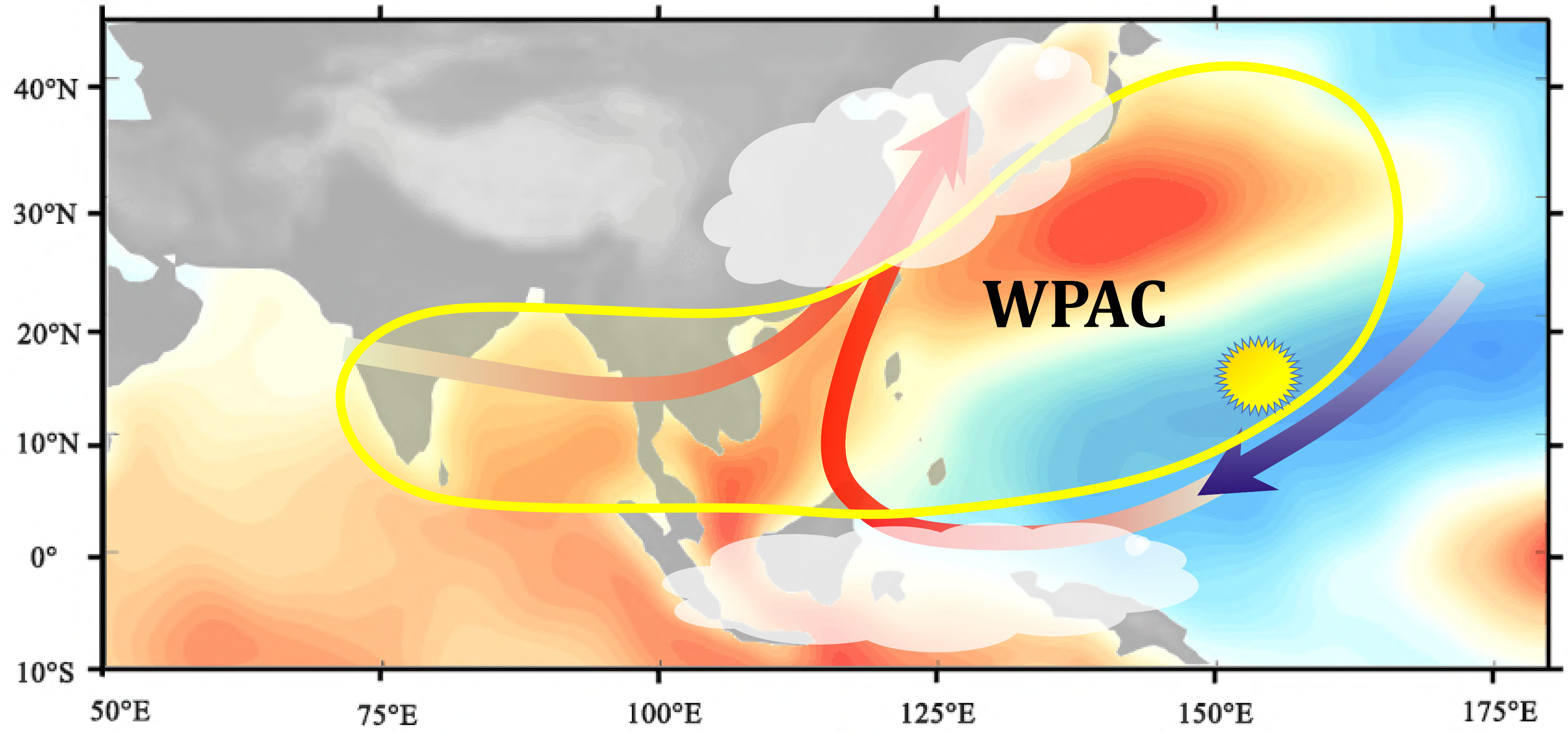
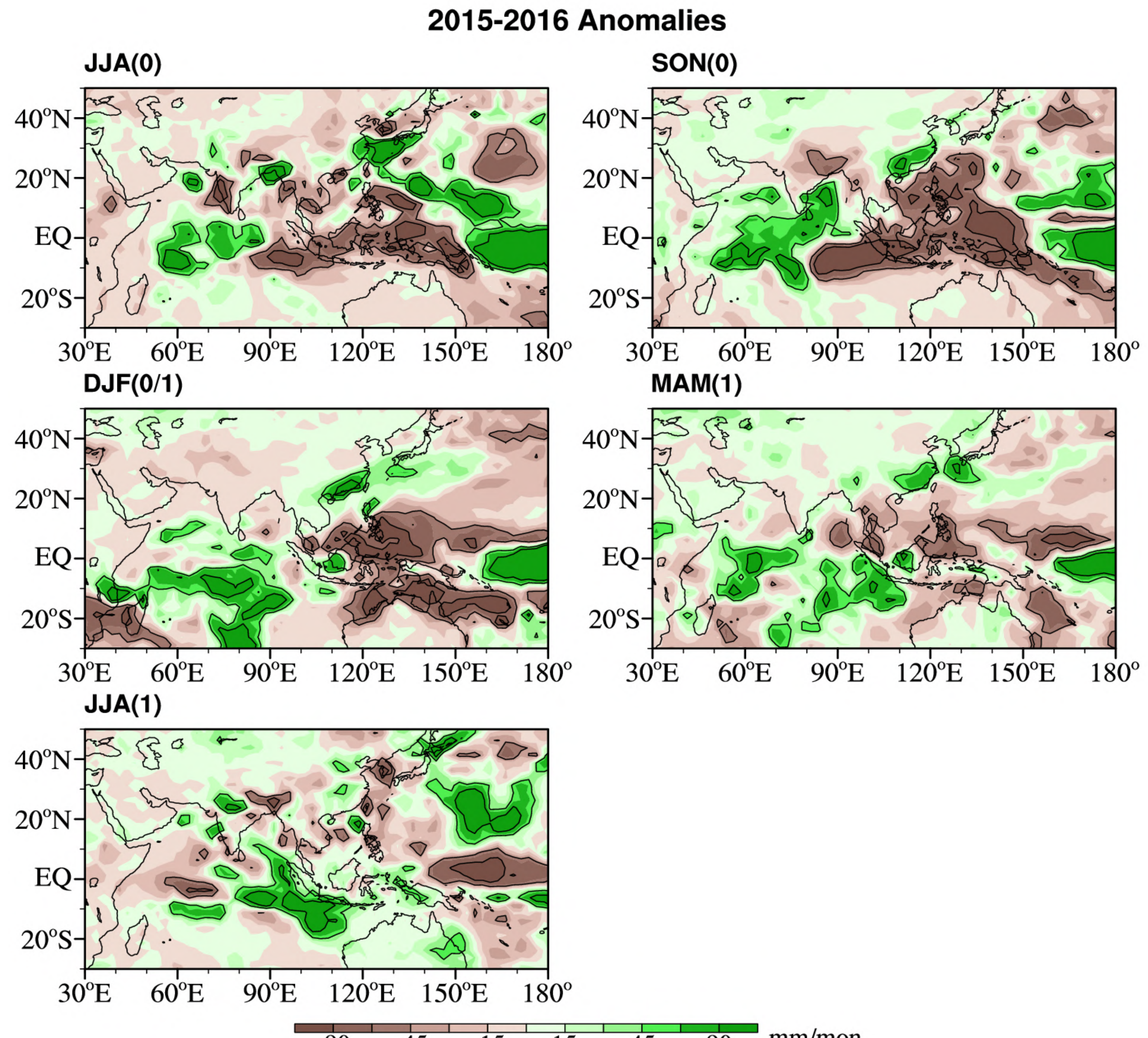


40°N
30°N
20°N
10°N
0°
10°S
50°E
75°E
100°E
125°E
150°E
175°E
WPAC

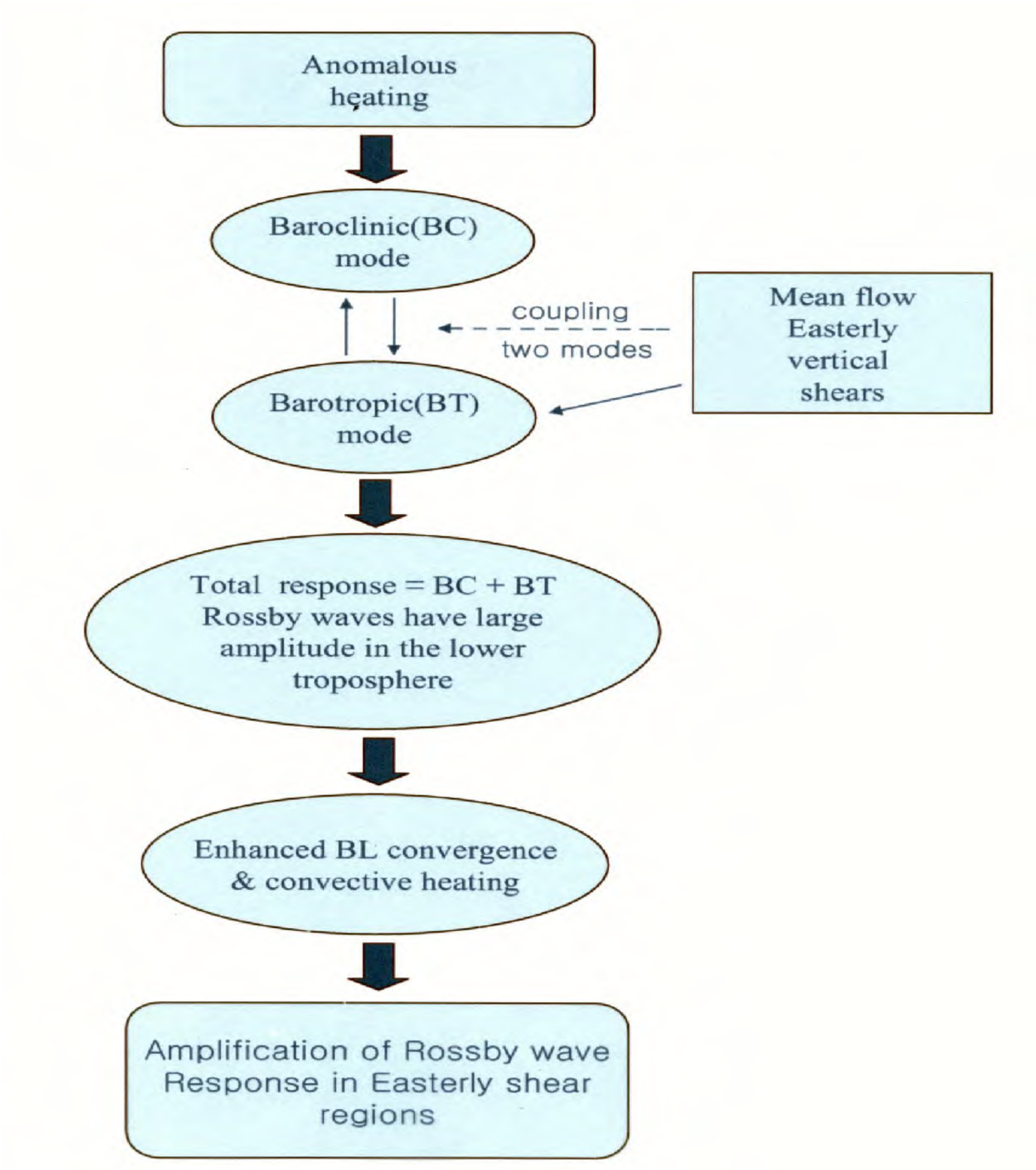



# Observed AAM rainfall anomalies during 2015-16 El Nino

Deficient monsoon rainfall is wide spread over western India, Indonesia, Philippines, and northern Australia from JJA(0) to DJF (0/1).

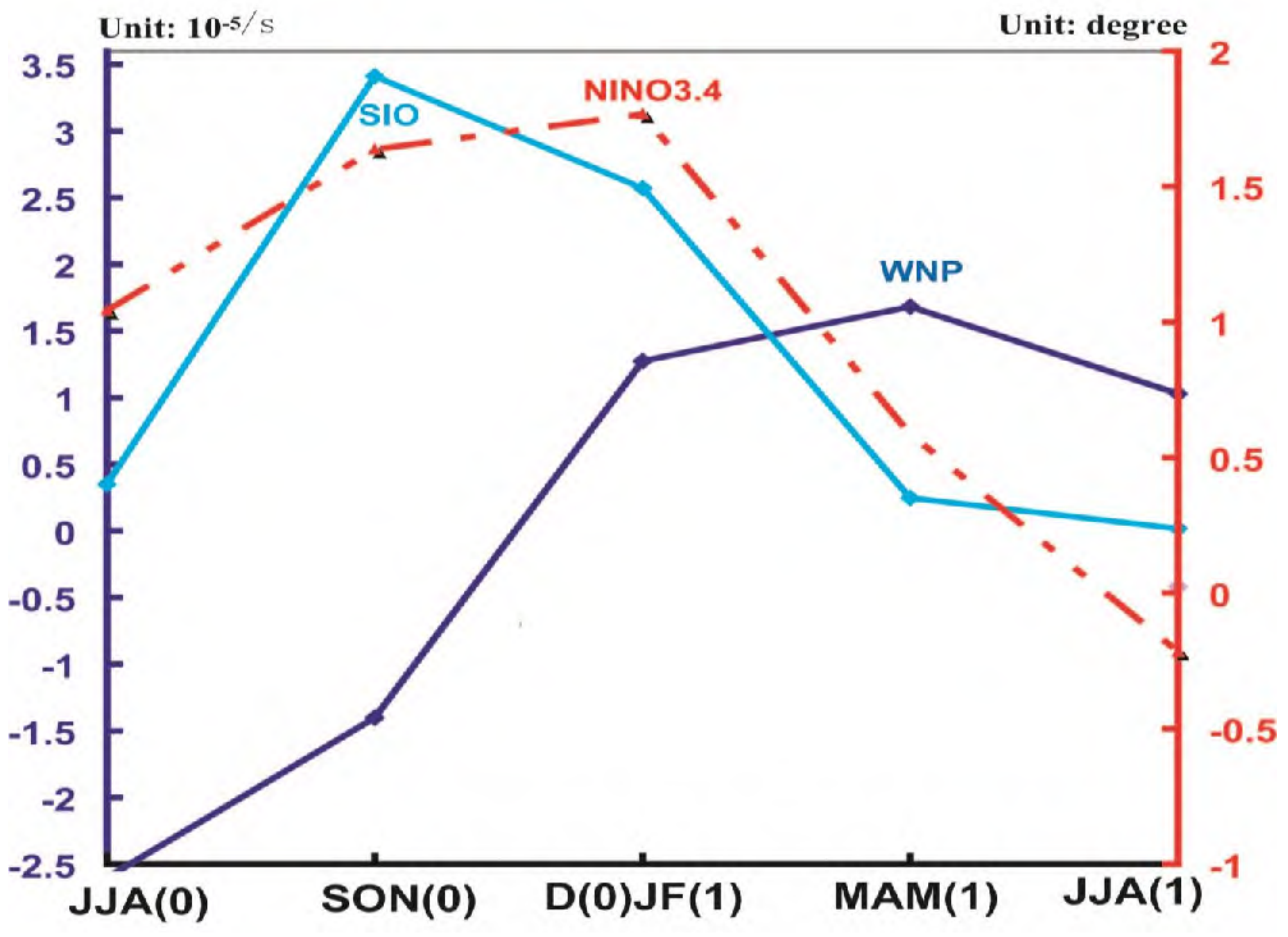
Enhanced rainfall along the East Asia subtropical front are noticeable from SON(0) to JJA(1).

GPCP data




Monsoon easterly vertical wind shear can enhanced Rossby wave response, therebygenerate asymmetric ENSO teleconnection (Wang and Xie 1996)

# Evolutions of the WNP AC and SIO AC cannot be fully explain by remote El Nino forcing




Evolution of SIO AC and WNP AC anomalies

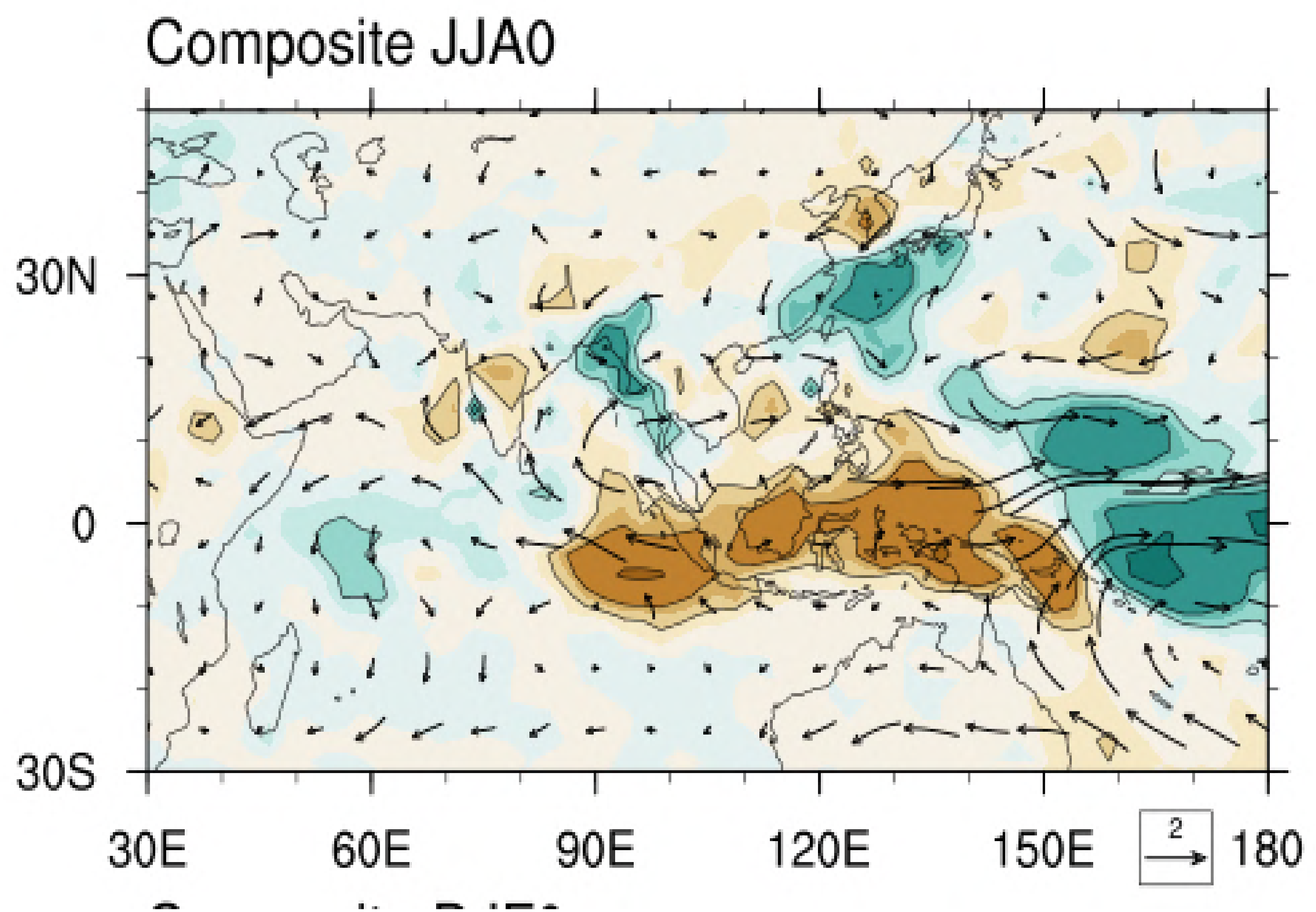
The two ACs are not in phase with evolution of El Nino.

- WNP AC emerges in SON(0), mature in DJF(0/1), peaks in MAM(1) and maintains until JJA(1).

- SIO AC emerges in JJA(0), peaks in SON(0), and decay in DJF(0/1).

Wang et al. 2003

# Composite AAM rainfall anomalies for three super El Nino events

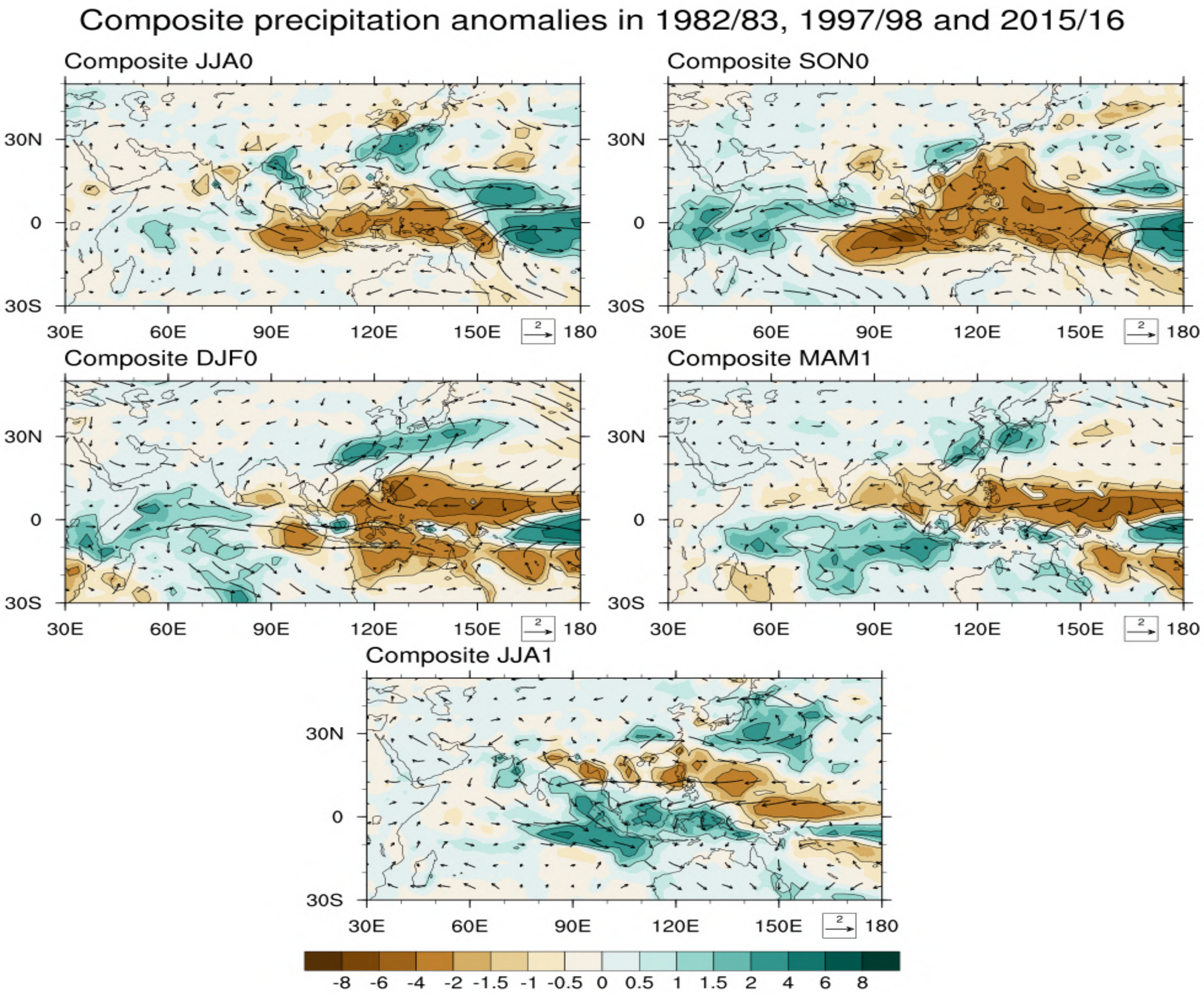



In EAM sector, there are increased rainfall along the EA subtropical front from JJA (0) to JJA(1).

Are these features typical to other El Nino events?

The composite seasonal precipitation (shaded) and u- v-wind (vectors) anomalies for three super El Ninos: 1982/83, 1997/98, and 2015/16. The contours are 1.2.4 mm/day. GPCP data are used.

# Composite AAM rainfall anomalies for three super El Nino events

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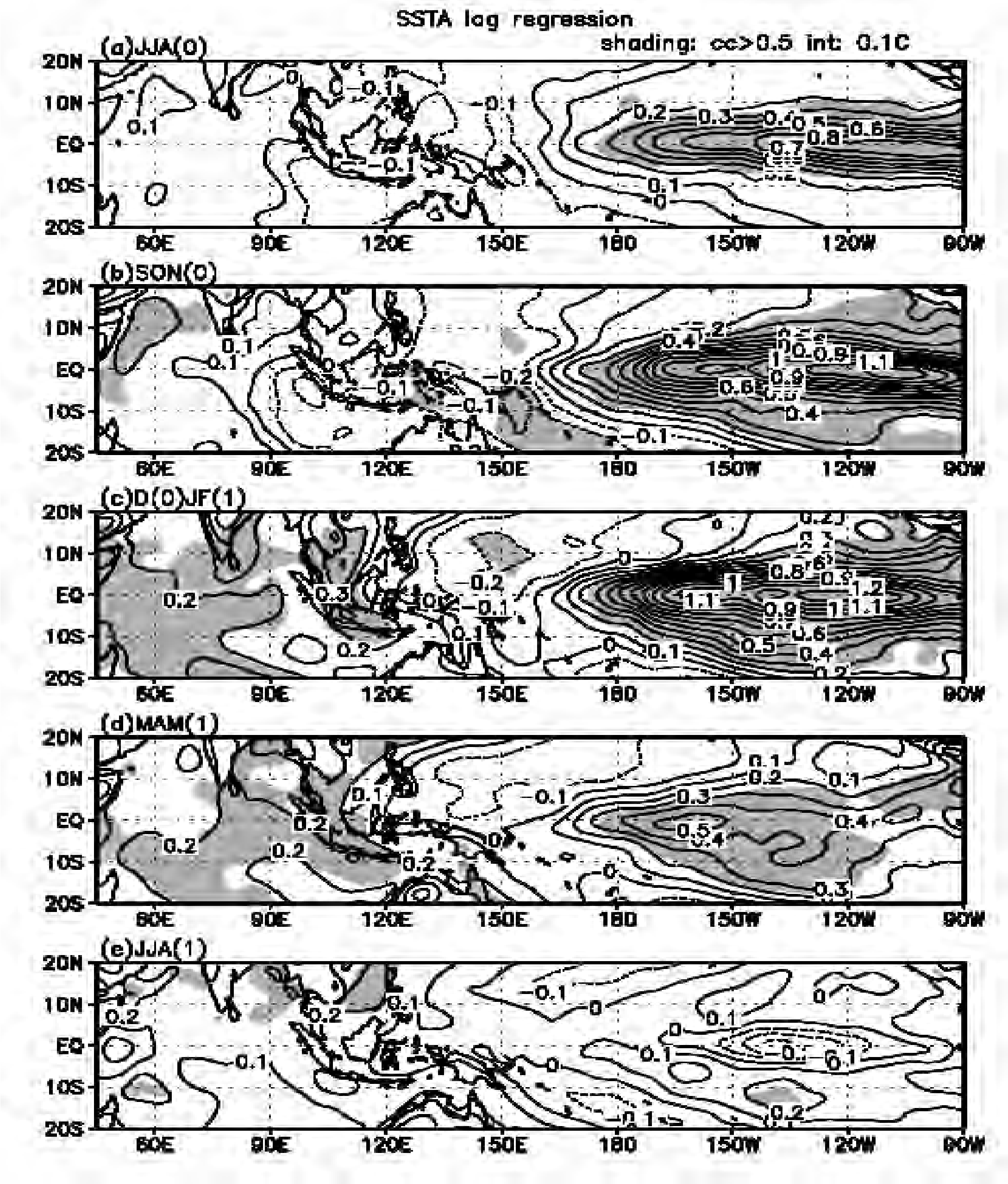
# Relation with Indo-Pacific SSTA




**ENSO Impacts?**
**Yes.**

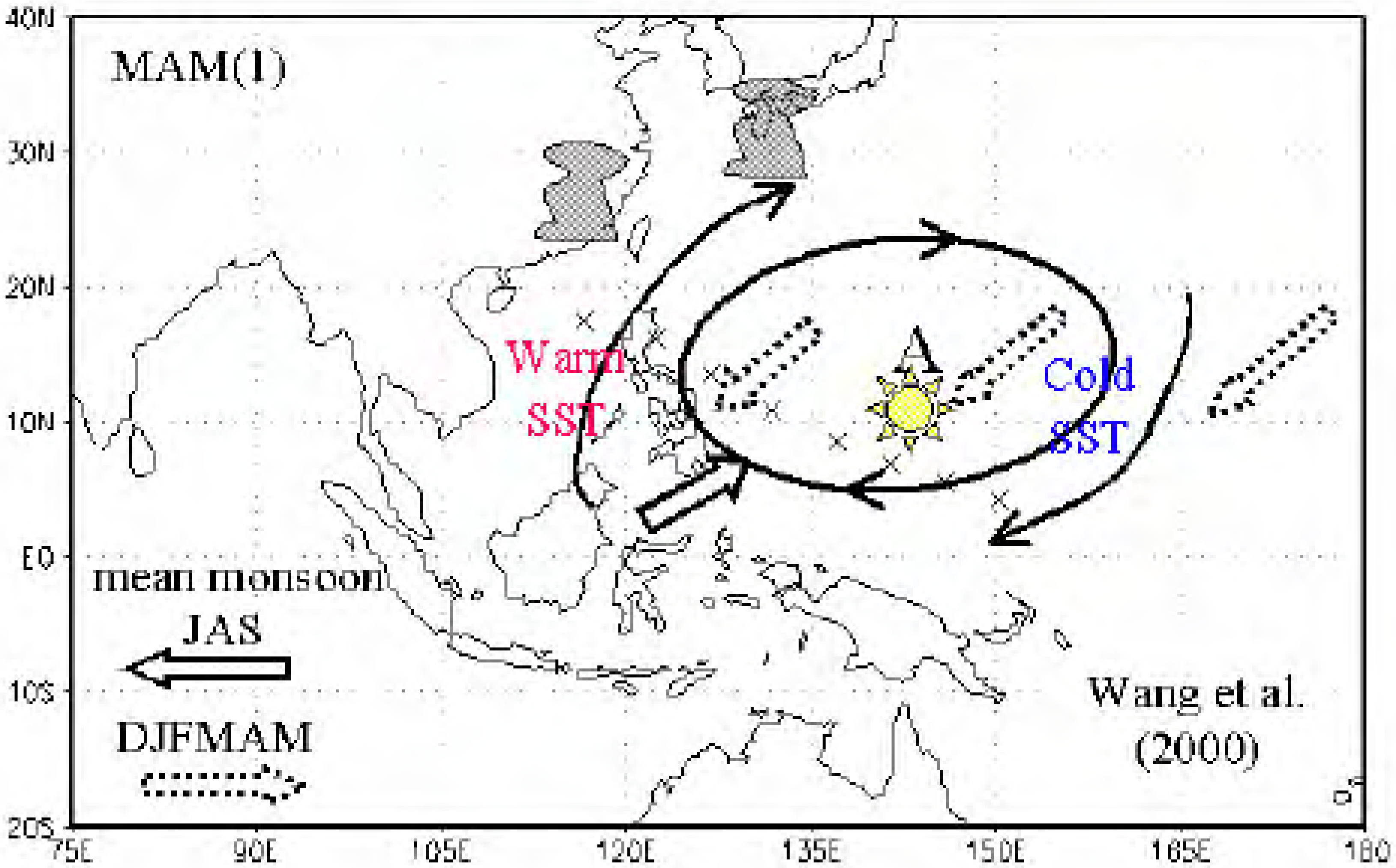
**But**

**Can ENSO impacts fully explain the AAM variability?**

**No.**

**Why?**
**Phase relationship between two ACs and Nino 3.4**

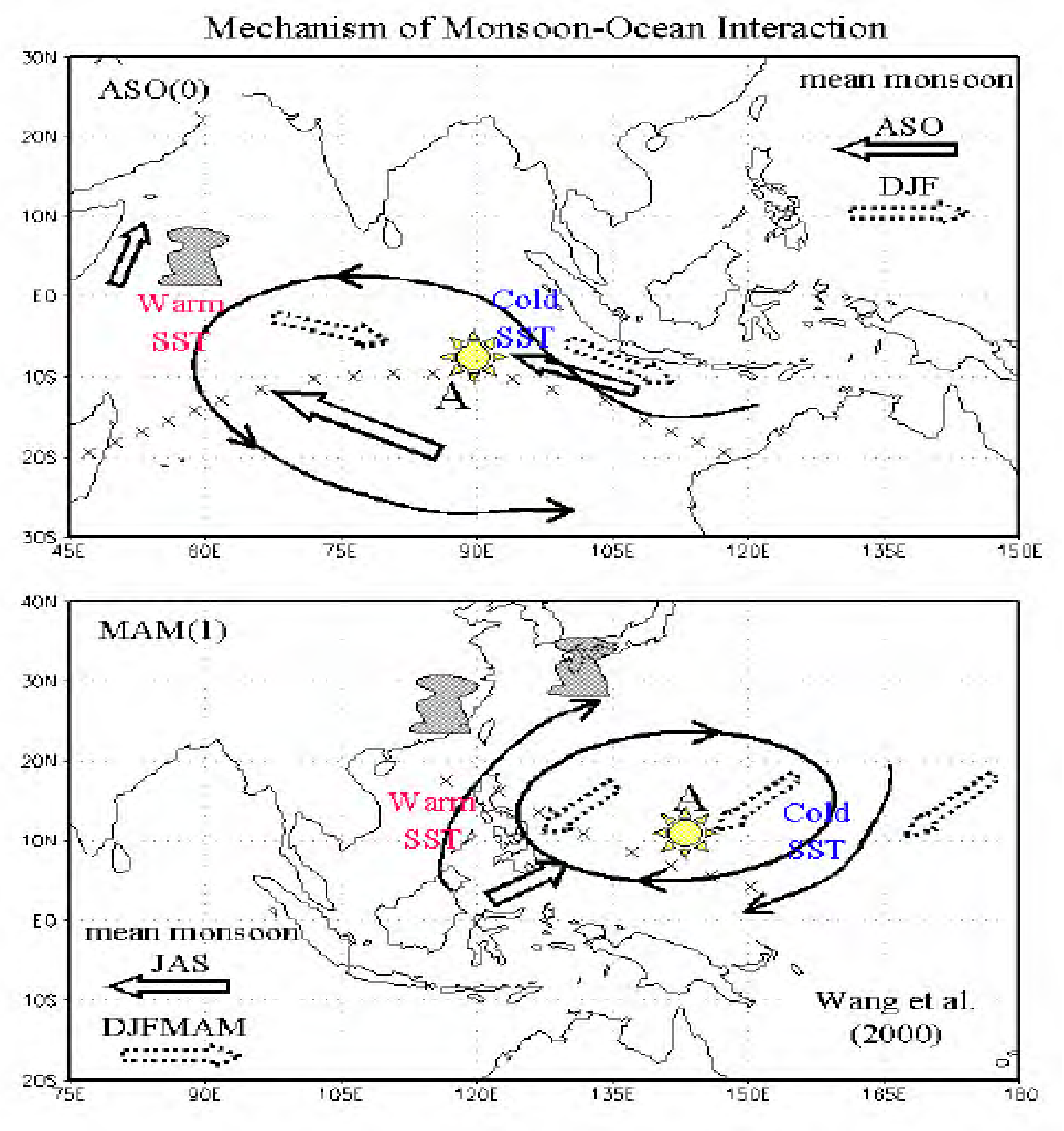
# Why strong El Nino has a "delayed" impact on EASM in JJA(1)




WNP Subtropical High and Indo-Pacific SST coupled Mode

Monsoon-ocean interaction in the WNP maintain AC anomalies into JJA(1), providing a "delayed" impact.

# Why does the SIO AC anomaly mature in the fall before ENSO peak phase?




## Off-equatorial RW-SST feedback

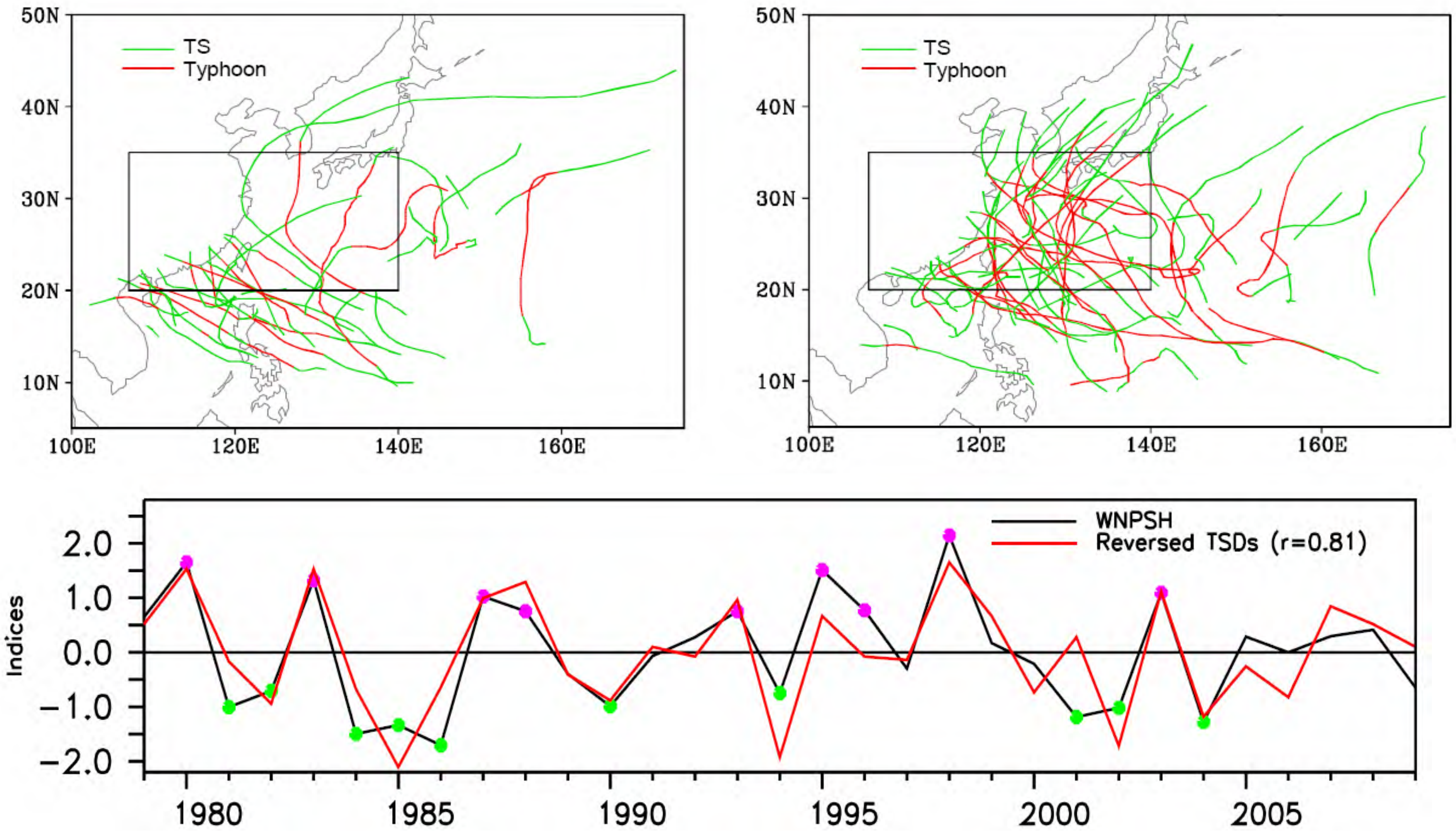
### SIO AC

Positive feedback from summer (0) to fall (0), but negative feedback from fall(0) to following winter. SIO AC and IOD peaks in fall.

### WNP AC

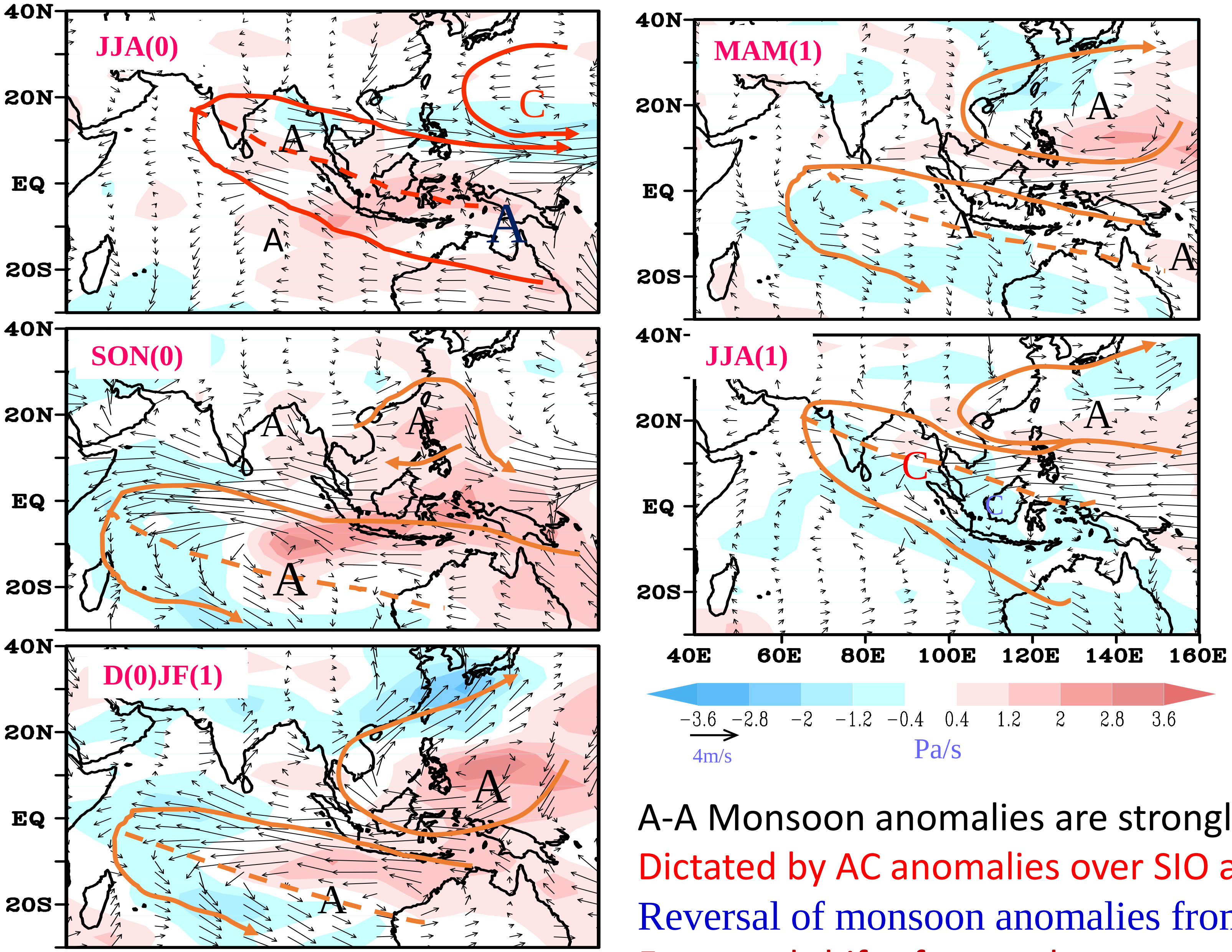
Positive feedback maintains AC and SST dipole *after mature El Niño* , providing a delayed impacts on EASM.

# Contrast for the TS tracks in the 4 extremely strong WPSH years (left) and 4 extremely weak WPSH years (right).




Wang et al. 2013

# Contrasting AAM anomalies from JJA(0) to JJA (1)




First S-EOF mode: 850hPa winds and 500hPa ω

(Red: Suppressed Precipitation)

Wang et al. 2003

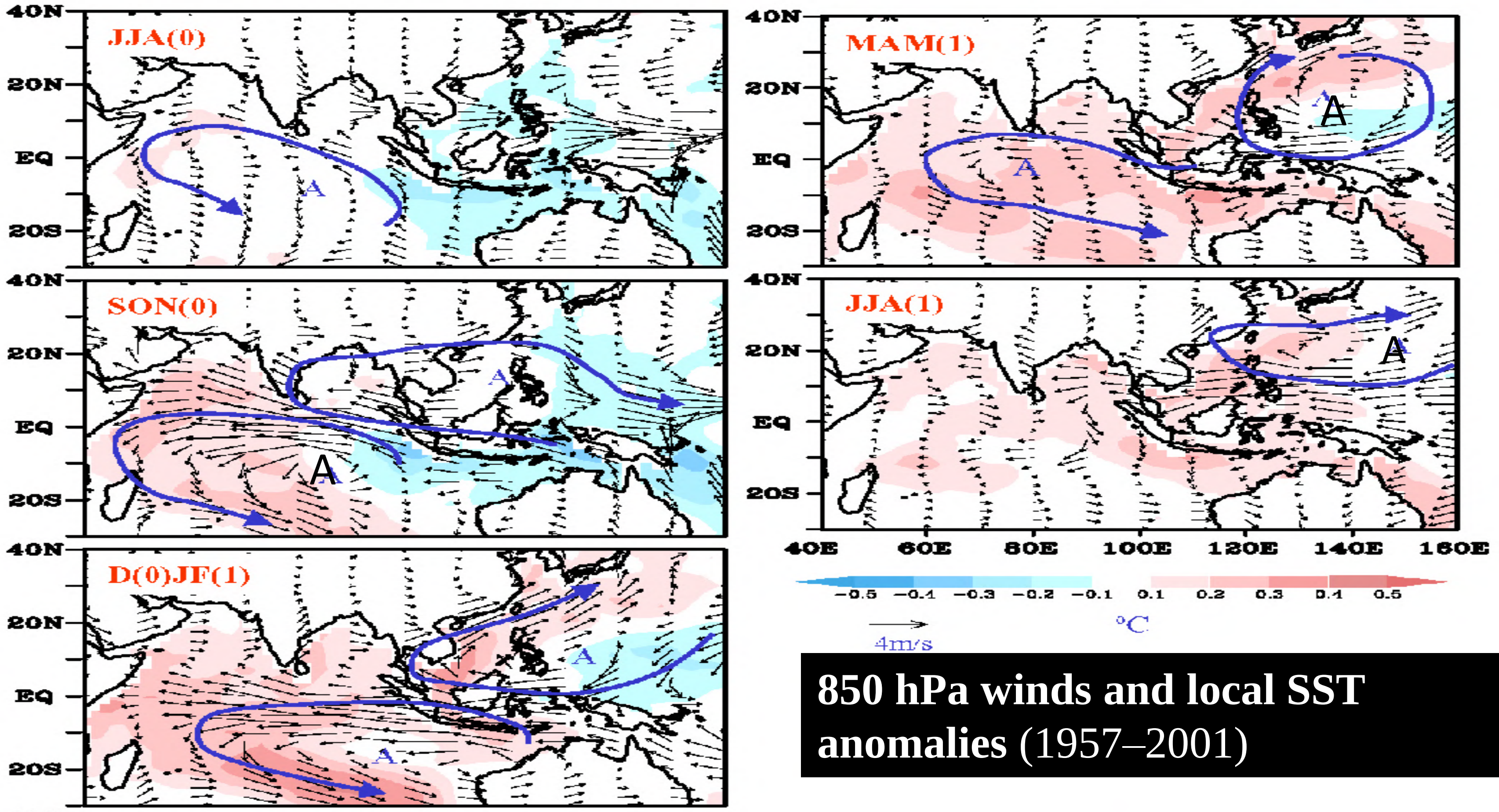
A-A Monsoon anomalies are strongly season-dependent

Dictated by AC anomalies over SIO and WNP

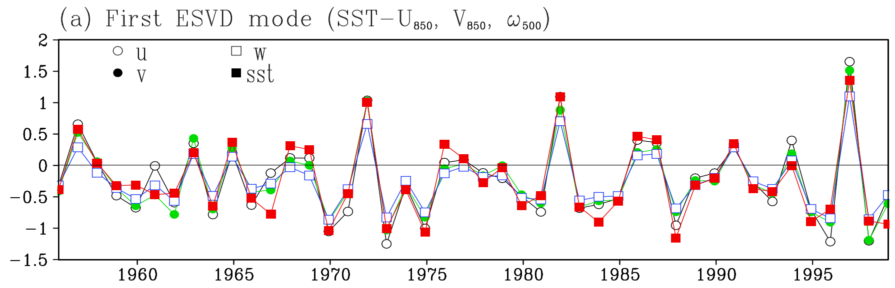
Reversal of monsoon anomalies from JJA(0) to JJA(1)

East ward shift of anomaly centers

# Role of Monsoon-Ocean interaction

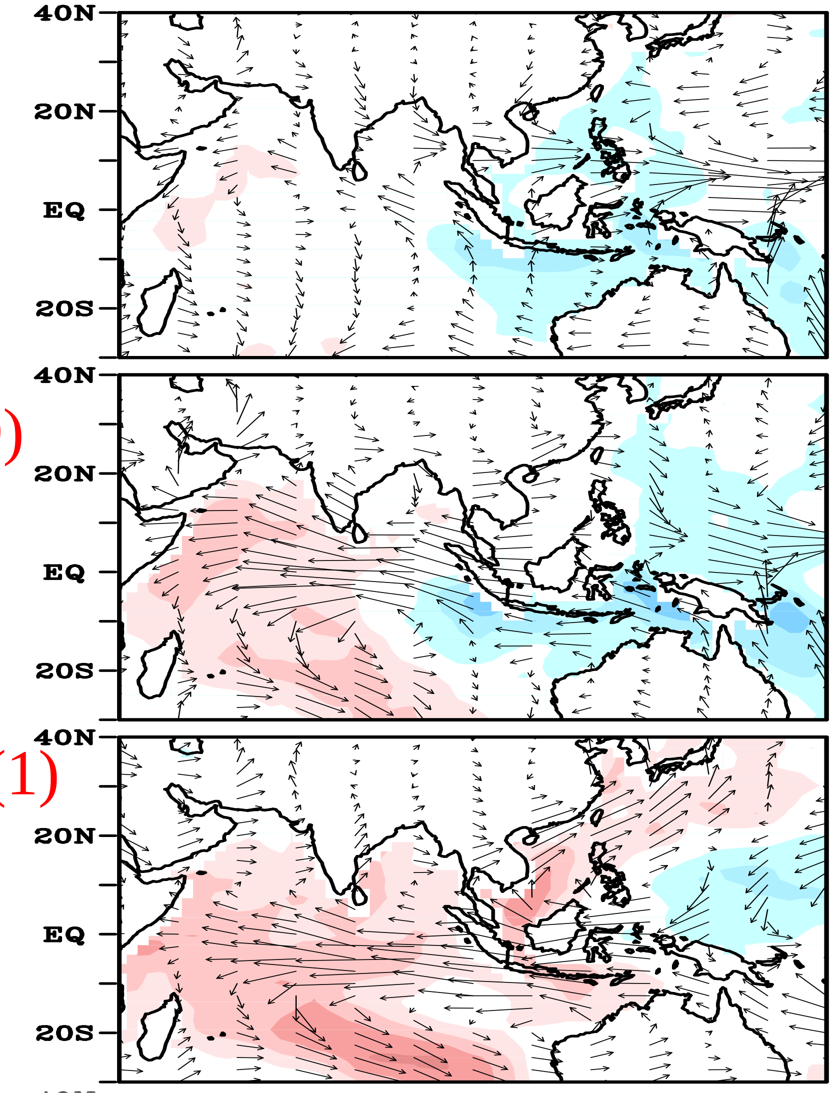



**850 hPa winds and local SST anomalies** (1957–2001)

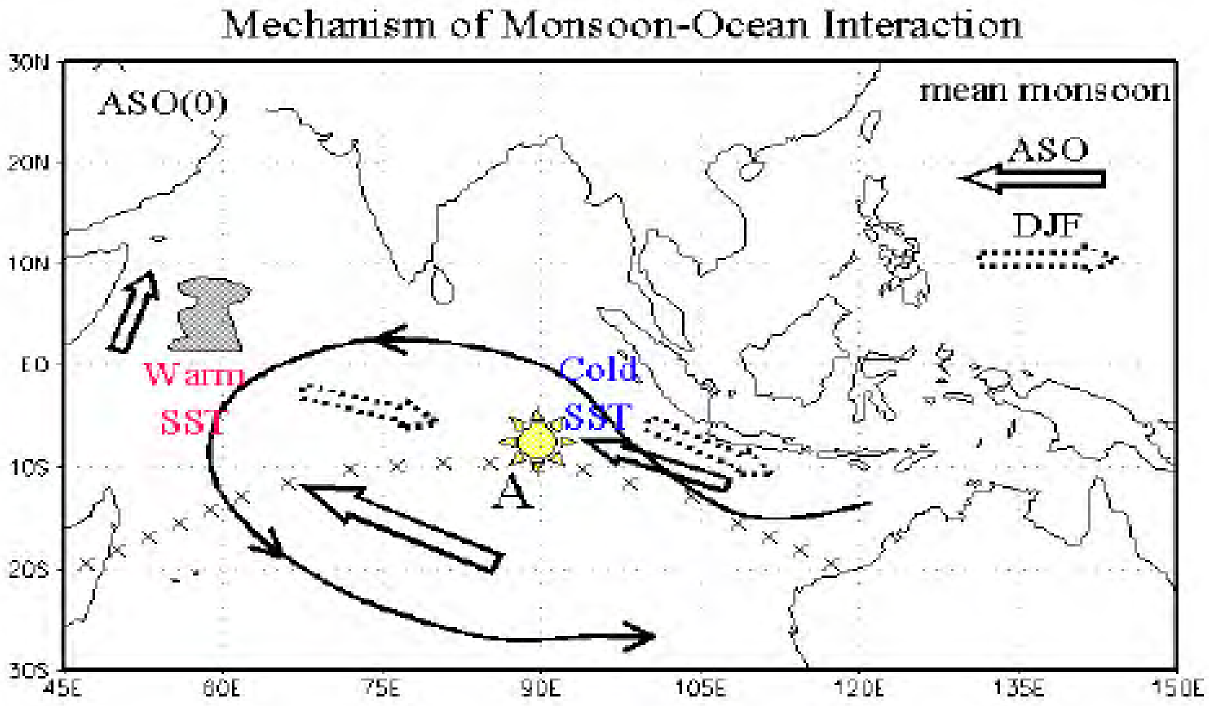



- •WNP AC emerges in SON(0), coupling with dipole SSTA, peaks in MAM(1) and maintained to JJA(1)
- •SIO AC emerges in JJA(0), coupling with IOD, Peaks in SON(0).

# Why does the SIO AC anomaly mature in the fall before ENSO peak phase?




Color shading: SSTA, vectors: 850 hPa wind anomalies



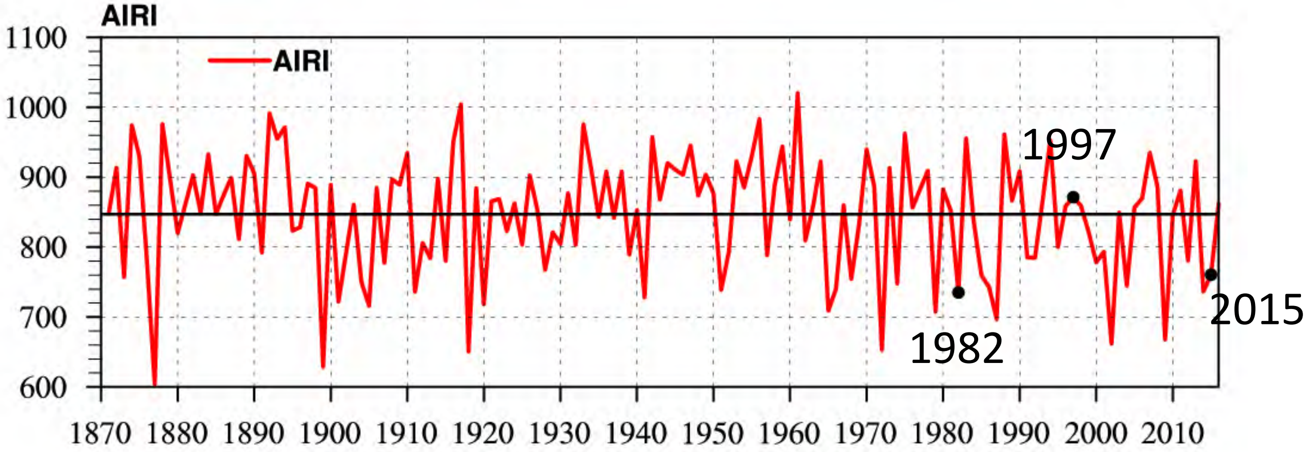

**SIO AC**

Season-dependent Off-equatorial Rossby wave-SST feedback: Positive feedback from summer (0) to fall (0), but negative feedback from fall(0) to DFJ.

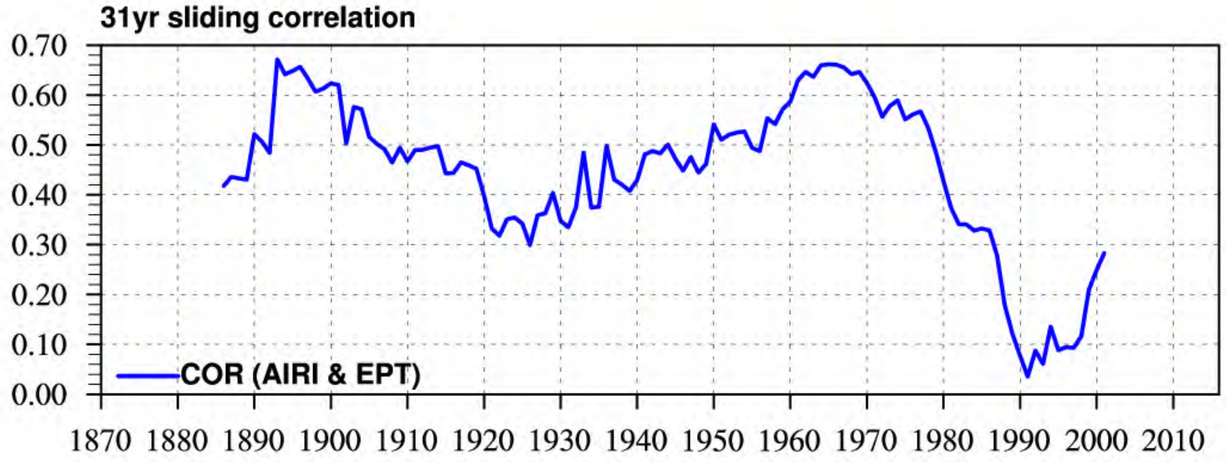
Development and decay of SIO AC

Wang et al. (2003), JC

# All Indian Rainfall in JJAS 2015




3 Super El Nino events do not cause terribly deficient ISM rainfall.

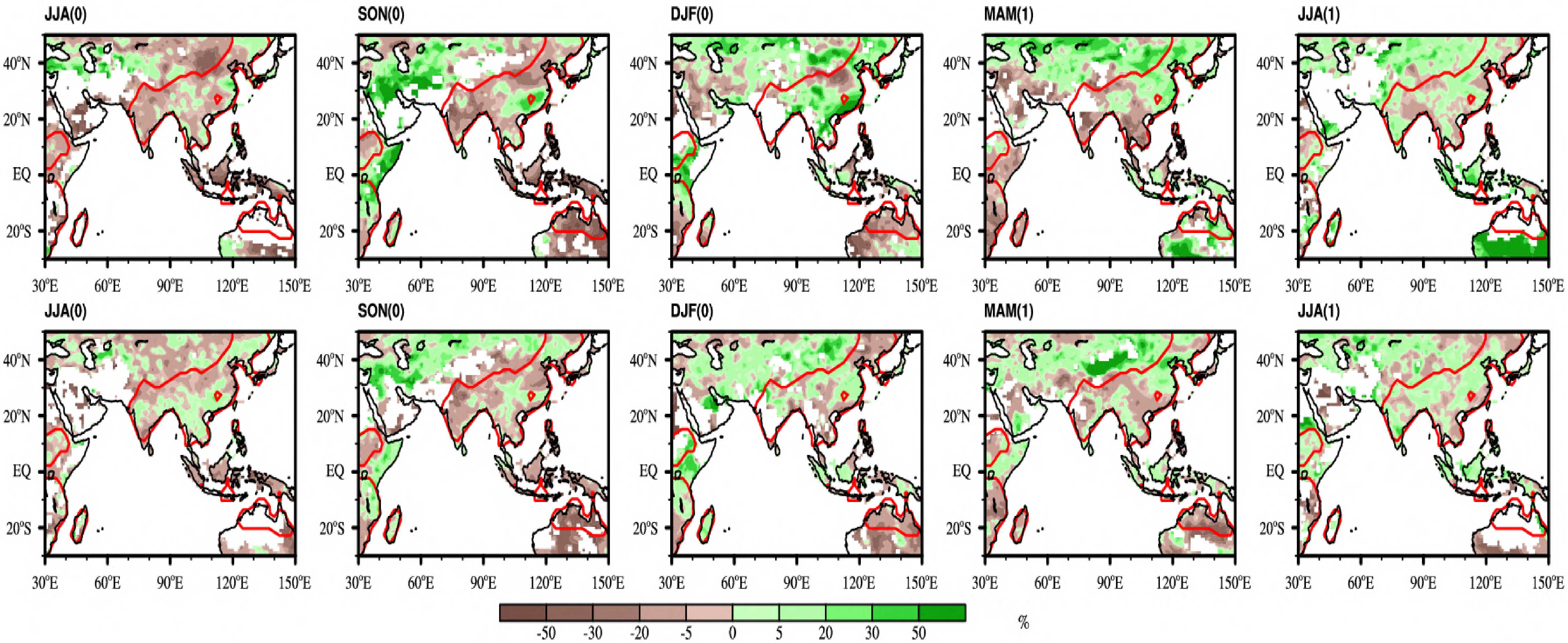



Time series of the 31-year central sliding correlation coefficients between AIRI and EPT (Wang et al. 2015).

# Composite precipitation percentage anomalies for strong and weak El Nino events

8 strong-super El Nino composite

10 moderate-weak El Nino composite




Central Asia dry regions: increase in precipitation from SON(0) to JJA(1).

The major differences between the strong and weak El Nino composite are (a) Central-western Indian rainfall during JJA(0); (b) Southern China rainfall anomalies duirng SON(0), DJF(0/1), and MAM(1).

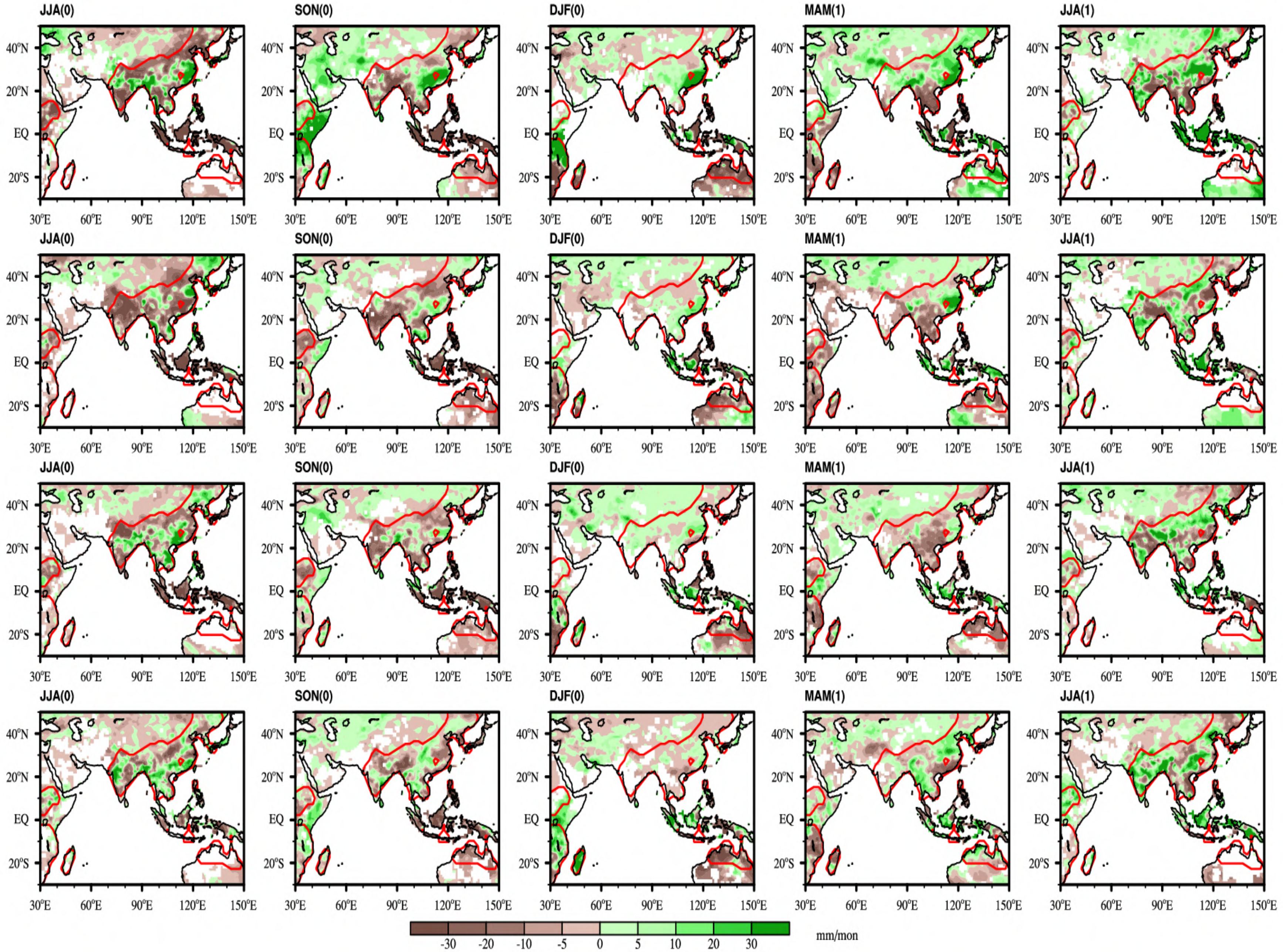
# Composite Precipitation anomalies for 4 composite El Nino events

3 super El Nino composite

5 strong El Nino composite

5 moderate El Nino composite

5 weak El Nino composite




Supper and strong Ninos share common features due to their similar evolutions.

But note JJA(0) ISM and MAM(1) Australian monsoon.

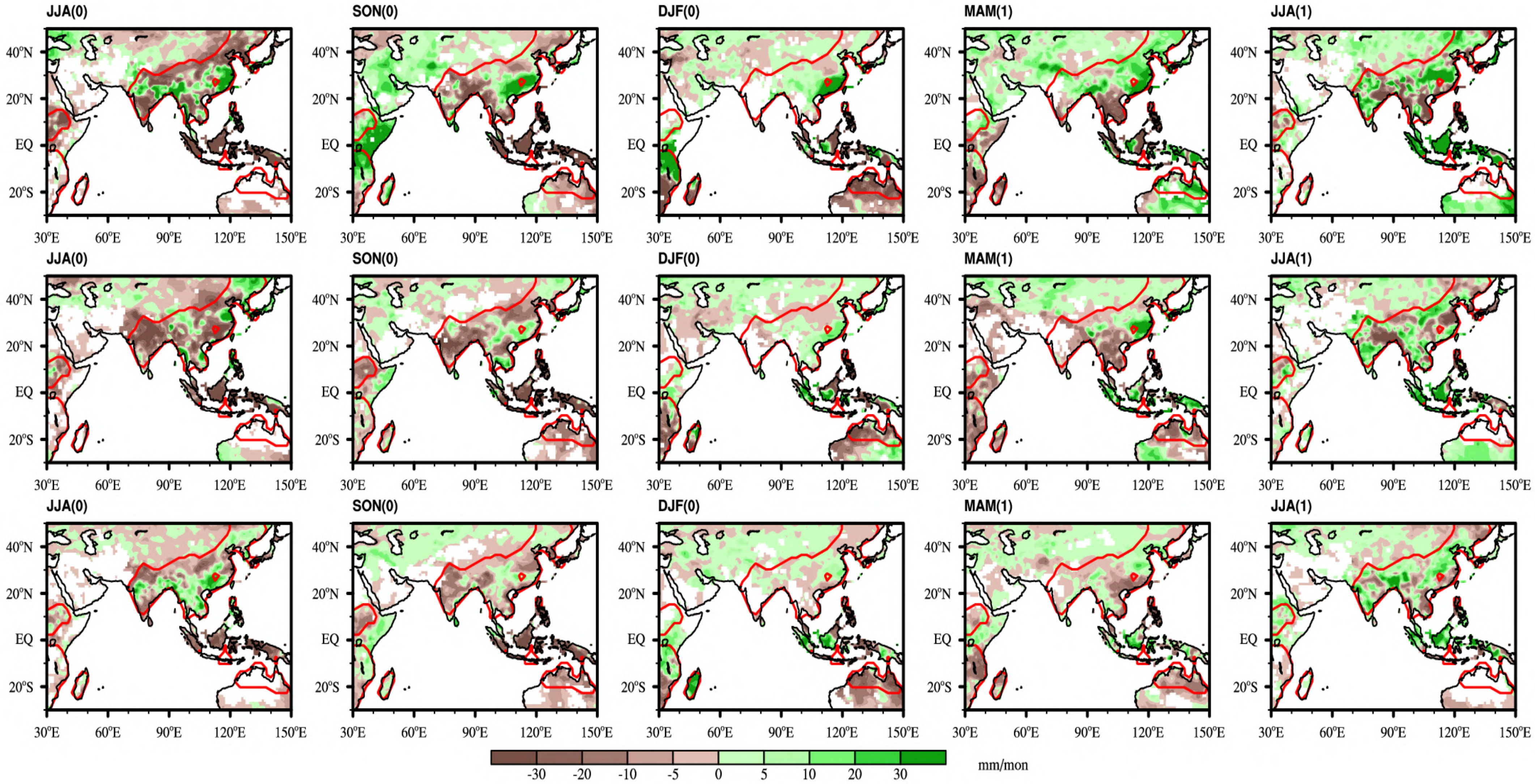
Moderate and weak Ninos are similar in Indonesian and Australian monsoon regions, but variable in Asian monsoon region

Precipitation anomalies

3 super El Nino composite

5 strong El Nino composite

10 moderate-weak El Nino composite



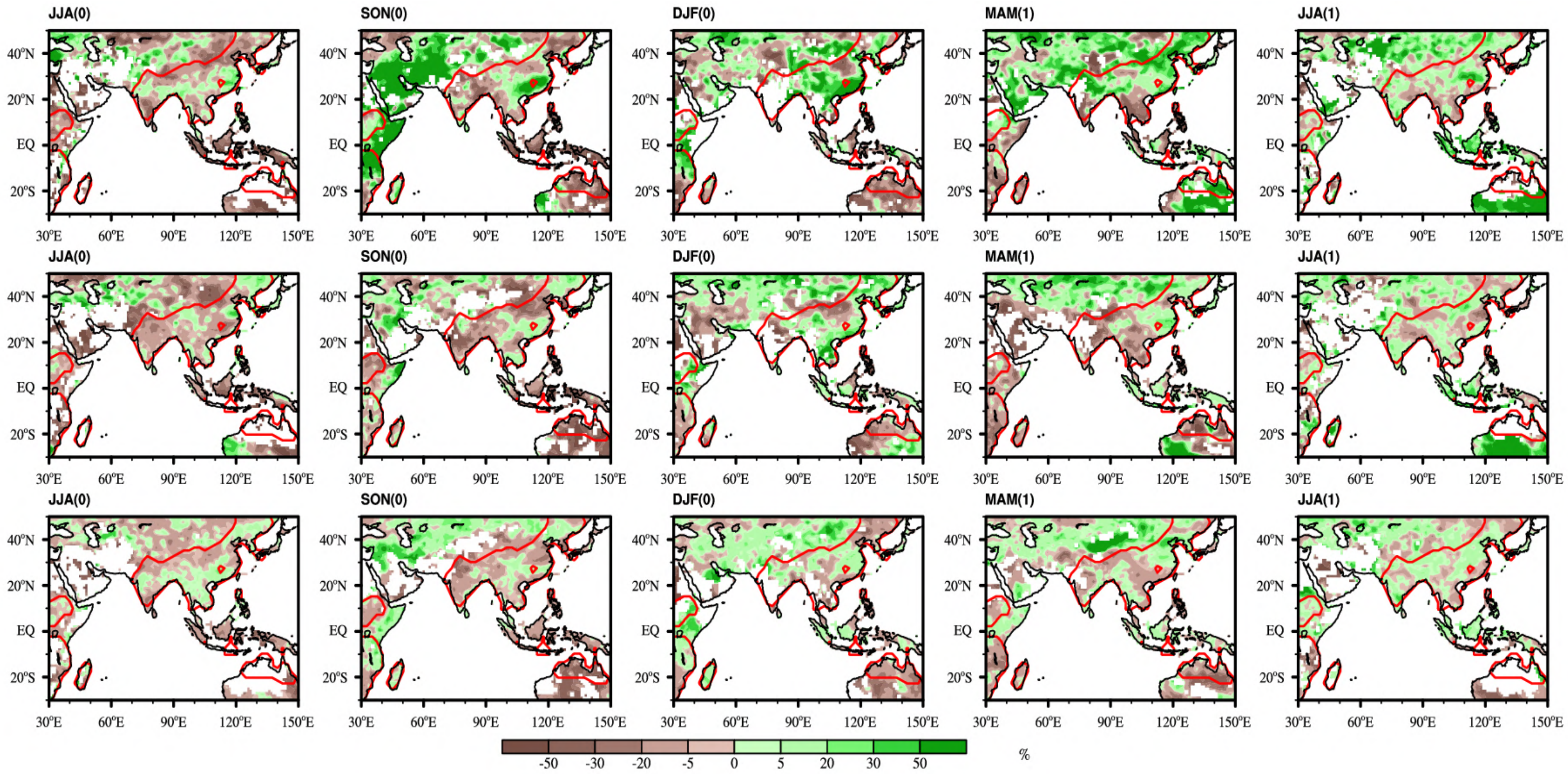

(Moderate El Nino years: 1986,1987, 1994, 2002, 2004 , Weak El-Nino years: 1963, 1968, 1969, 1976, 2006)

Precipitation percentage anomalies

3 super El Nino composite

5 strong El Nino composite

10 moderate-weak El Nino composite



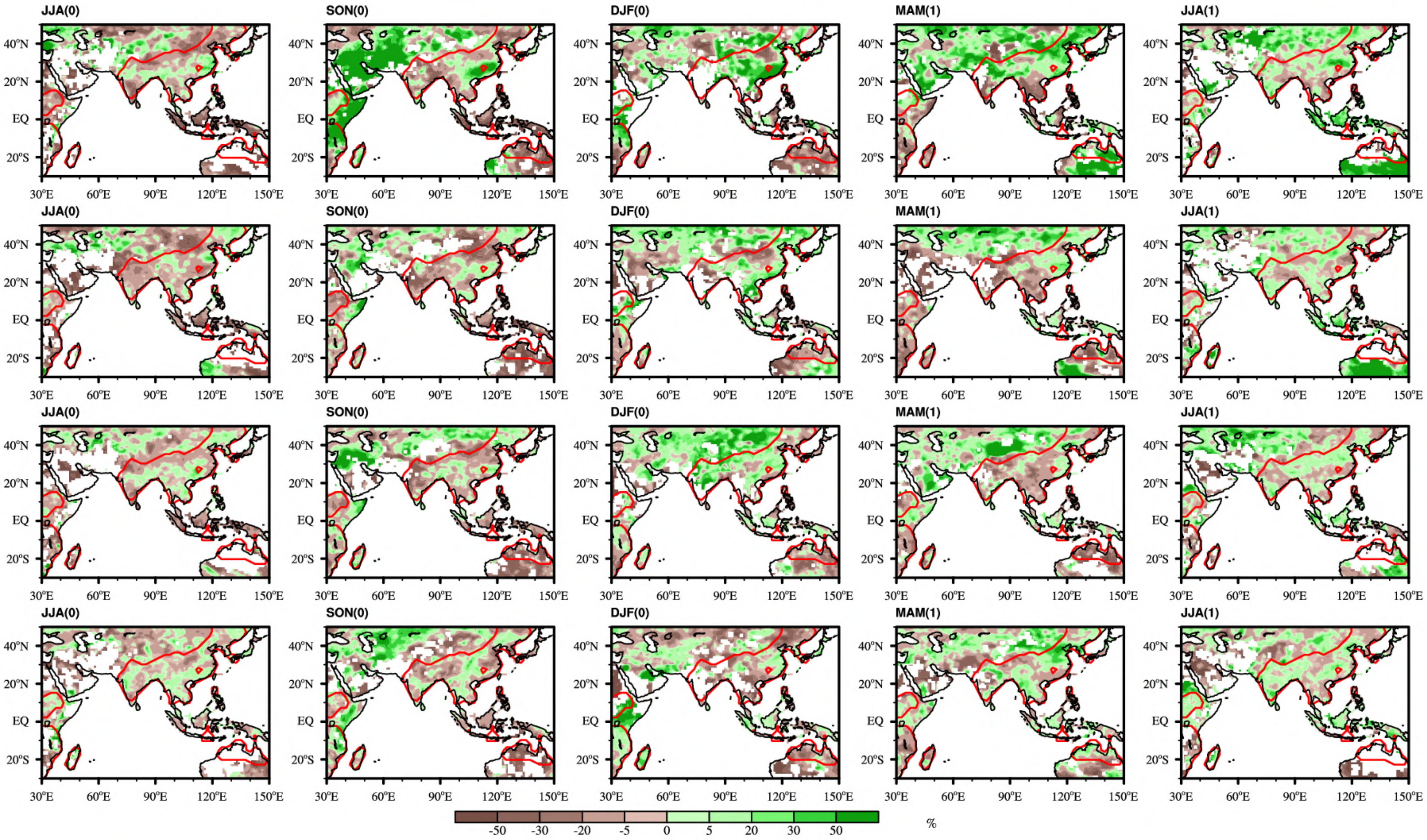
Precipitation percentage anomalies

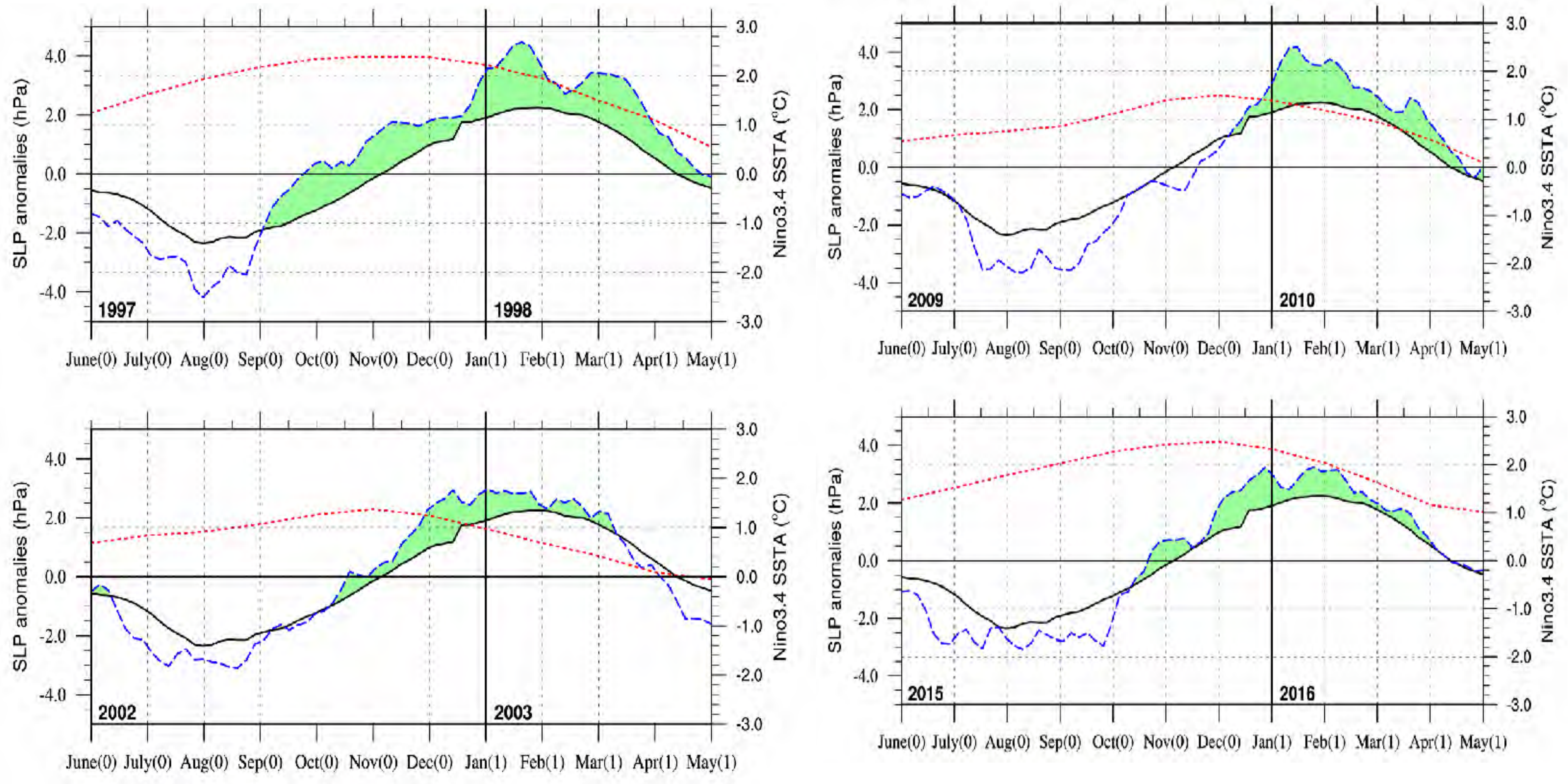
3 super El Nino composite

5 strong El Nino composite

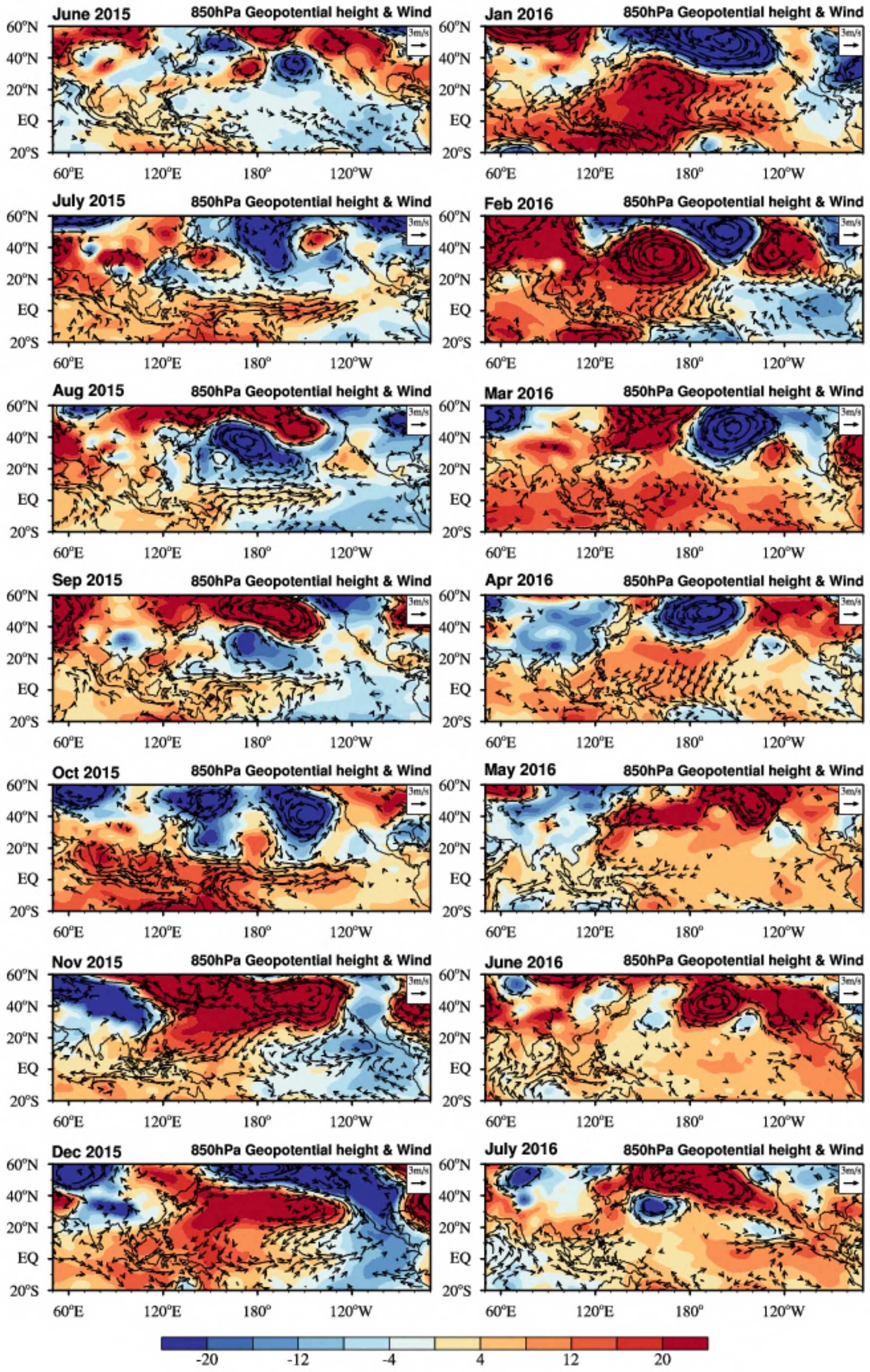
5 moderate El Nino composite

5 weak El Nino composite



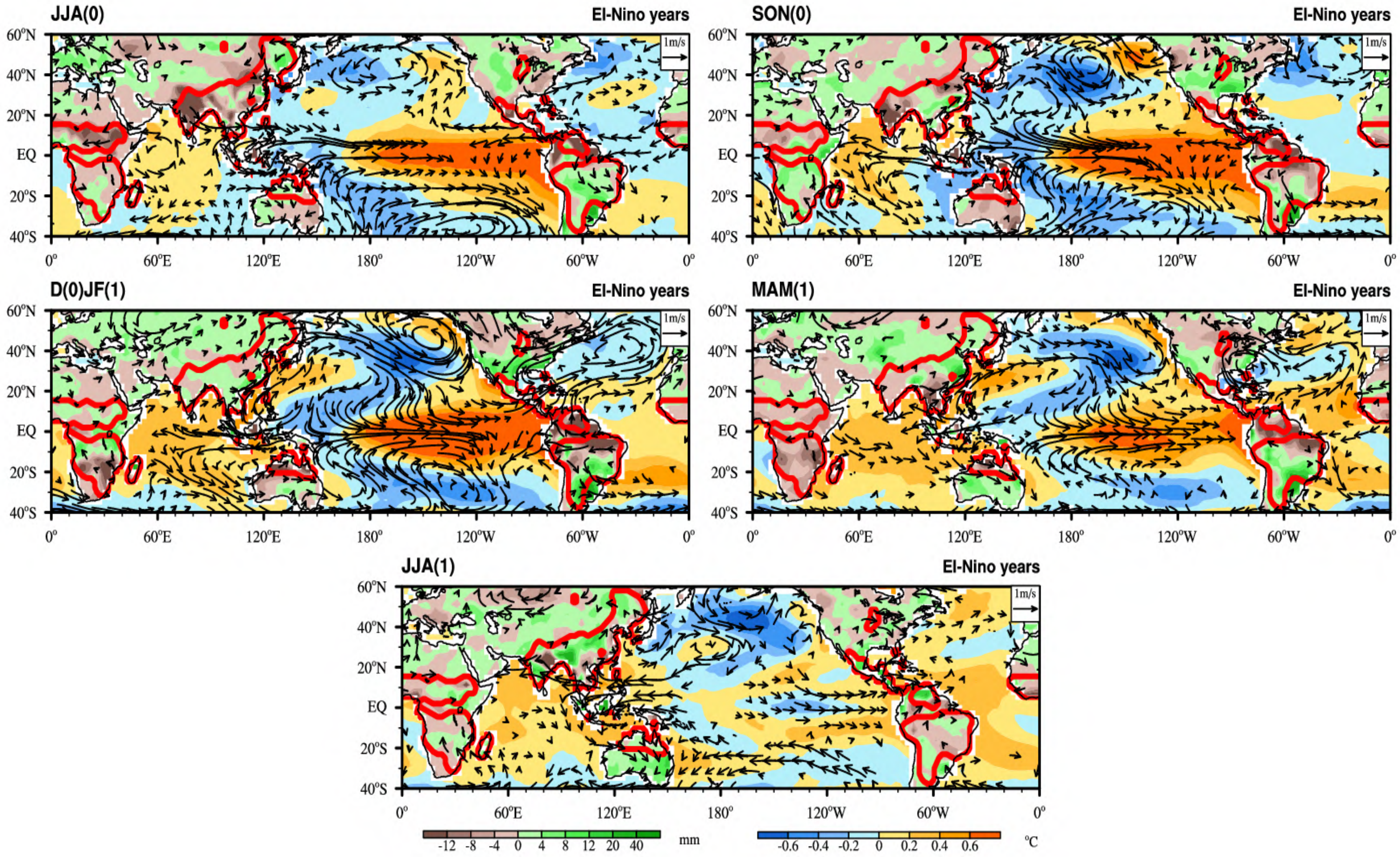



The 7-pentad running mean (blue dashed) and the climatological annual cycle (excluding the annual mean; black solid) SLP averaged over the western North Pacific region (10-20N,120-150E) for two major El Nino episodes 1997-1998,2002-2003, 2009-2010, 2015-2016. The red dotted curves are the corresponding 3-month running mean Nino-3.4 SST anomalies. The shading highlights the period during which the WNPAC persists. Anomalies are based on climatology for the period of 1957-1999 (same as Wang and Zhang(2002)).




850hPa Geopotential height (shading) and wind anomalies (vector) from June 2015 to July 2016. Anomalies are based on climatology for the period of 1991-2000. NCEP1 Reanalysis data are used.

# Composite map (JJA (0)-JJA(1)) for El-Nino years (10)




Composite global anomalies from JJA(0) to JJA(1) associated with Nino3.4 index based on monsoon year (June(0)-May(1)). The composite was made by the strong El-Nino averaged SST (shading over ocean), precipitation (shading over land) and 850hPa wind (vector) anomalies during the period of 1957-2014. The strong El-Nino was defined by Nino3.4 index above one standard deviation during 1957-2014.

Based on Monsoon year Nino 3.4, I classified El Nino as follows:
Supper El Ninos (3): 1982-83, 1997-98, 2015-16
Strong El Nino years (5): 1957, 1965, 1972, 1991, 2009
Moderate El Nino years (5): 1986,1987, 1994, 2002, 2004
Weak El-Nino years (6): 1963, 1968, 1969, 1976, 1977, 2006

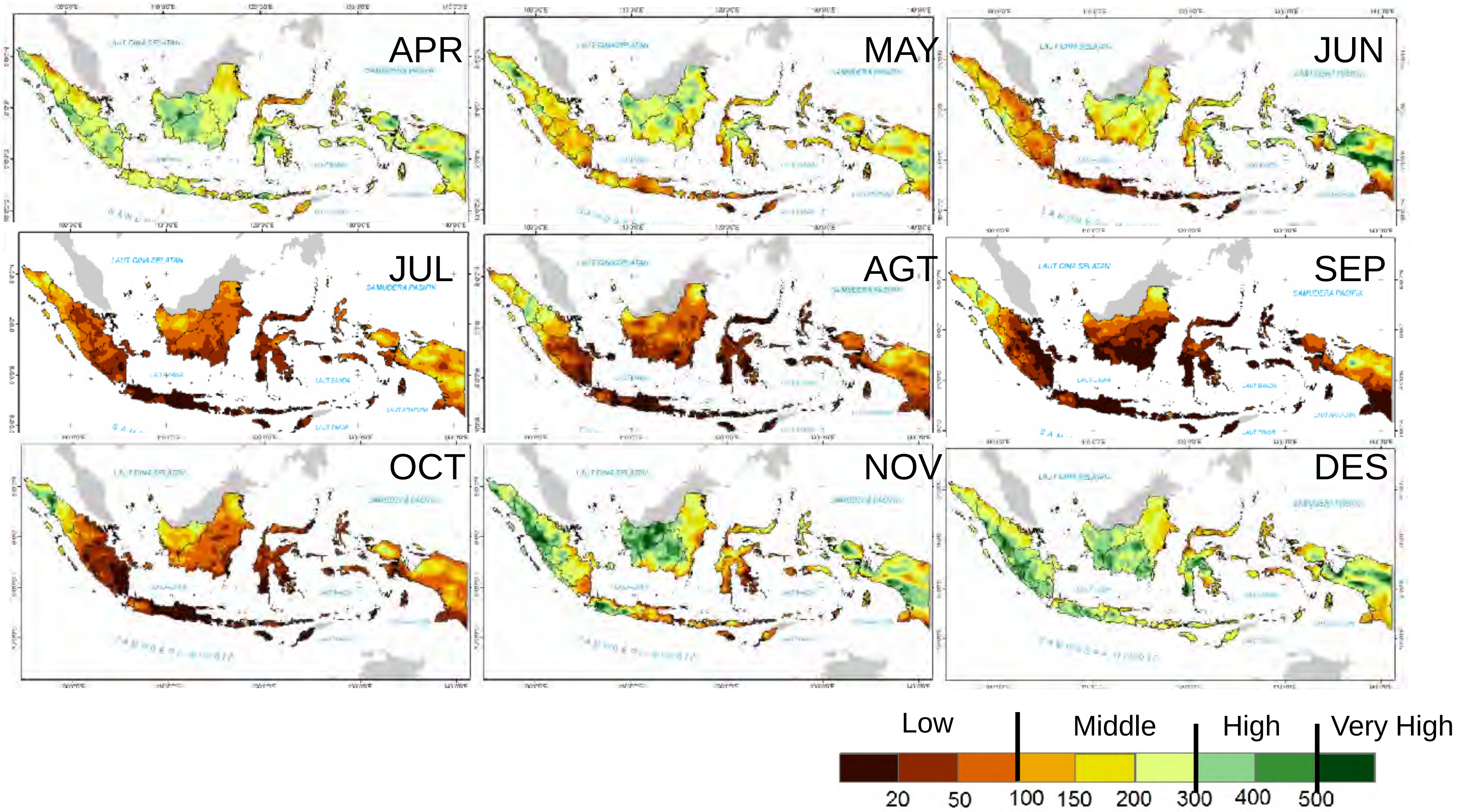
Based on ONI, I would classify El Nino as follows (slightly different from theirs)
Super (3): 82,97,15
Strong (5): 57, 65,72, 87, 91,
Moderate (4): 63,86, 02, 09
Weak (7): 68, 69, 76, 77, 94, 04, 06.

Therefore, the difference is small. In common, we may propose
Super (3): 82,97,15
Strong-moderate (9): 1957, 1963, 1965, 1972, 1986,1987, 1991, 2002, 2009
Weak (7): 1968, 1969, 1976, 1977, 1994, 2004, 2006,

Could you revise the last figure (slice9) by modify the domain as (30S-50N, 30E-150E) and compare (a) 2015-2016, (b) three super composite, (c) strong-moderate composite, and (d) weak El Nino composite? In each figure plot only those precipitation anomalies that the composite mean greater than the SD.

# Indonesia: Drought in July-October 2015

*From July- October 2015, the rainfall amount in southern part Indonesia decreased down to only 0-20 mm/month*



# Australia: Drought

**Drought** in November, 2015 in South **Australia**.

From: http://www.abc.net.au/news/2015-11-17/drought-stricken-south-australian-farmers-endure-with-no-relief/6946916

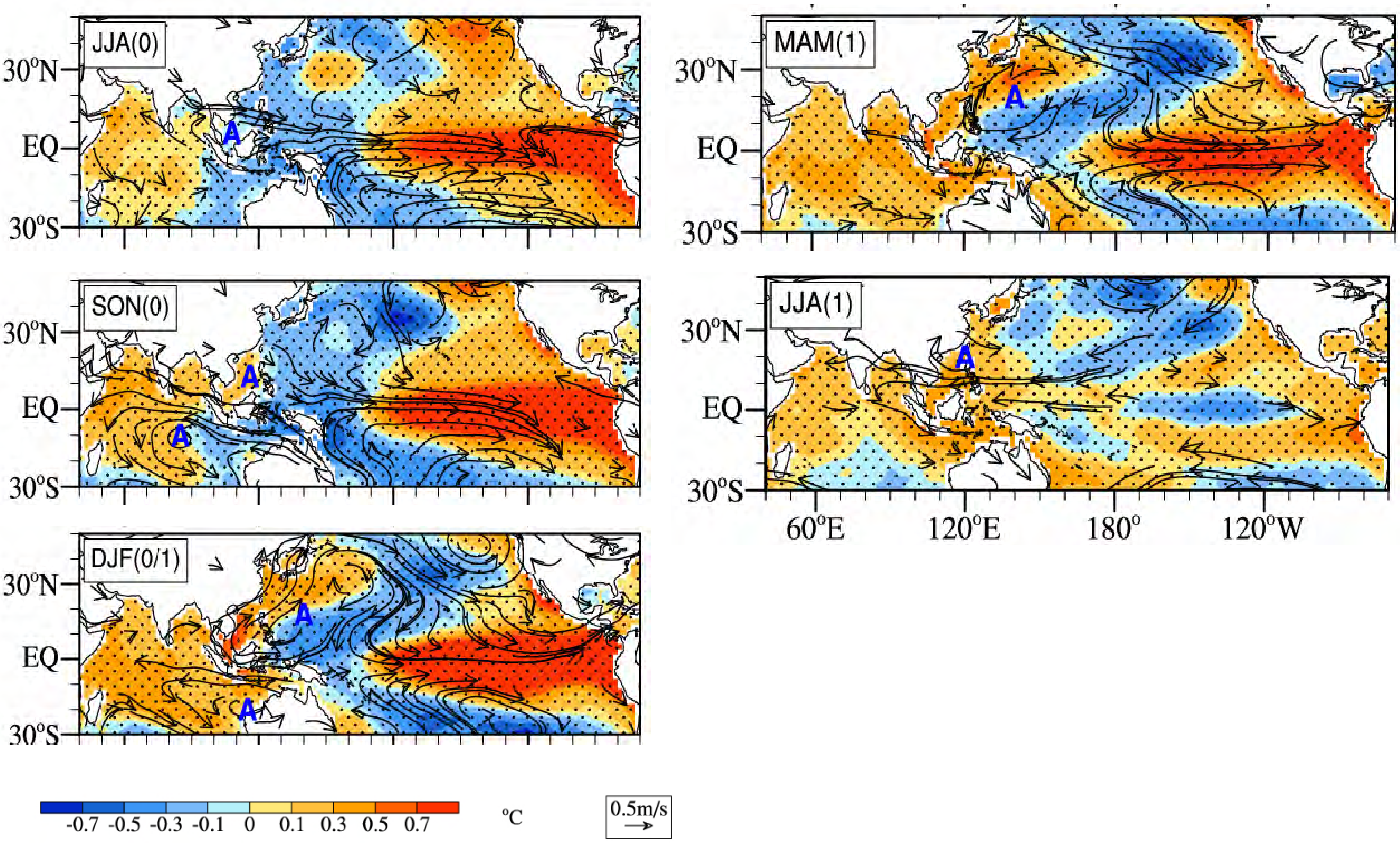
# India: Drought in April-May 2016

Temperatures in the **India** have soared to 51C, the **highest** in the country's recorded history, and the **third-highest** temperature ever documented on Earth.

Villagers in Shahapur throw containers into a well on May 13, 2016.


A farmer poses in his dried-up cotton field in Nalgonda, India, on April 25, 2016.

From: http://edition.cnn.com/2016/05/04/asia/gallery/india-drought-crisis/index.html



JJA(0)
SON(0)
DJF(0/1)
MAM(1)
JJA(1)
A
30°N
EQ
30°S
60°E
120°E
180°
120°W
-0.7 -0.5 -0.3 -0.1 0 0.1 0.3 0.5 0.7
°C
0.5m/s