Institute of Atmospheric Sciences (IAP), Chinese Academy of Sciences (CAS)

Influence of the Southern Hemisphere Annular Mode (SAM) on East Asian Climate

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Advanced School on Tropical-Extratropical Interactions on Intra-Seasonal Time Scales

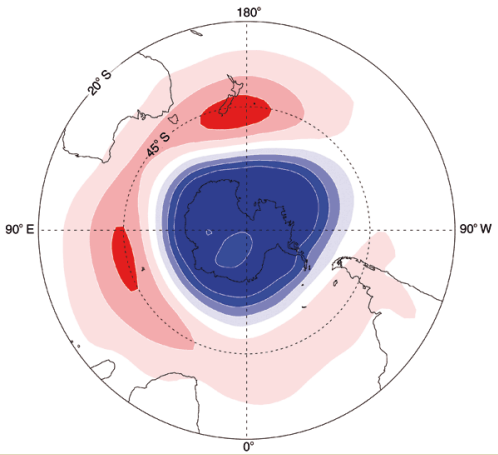
Outline

1. Background
2. Linkage between winter SAM & SCSP
3. Mechanism for the impact of winter SAM on SCSP
4. Winter SAM & spring zonal-mean precipitation
5. Summary and highlight

- SCSP: South China Spring Precipitation
- SOD: Southern Ocean Dipole

Background

The Southern Hemisphere Annular Mode (SAM), also known as the Antarctic Oscillation (AAO), is the principal mode of atmospheric circulation in the SH extratropics.



The SAM activity reflects a see-saw variation between air pressure in the middle and high latitudes.

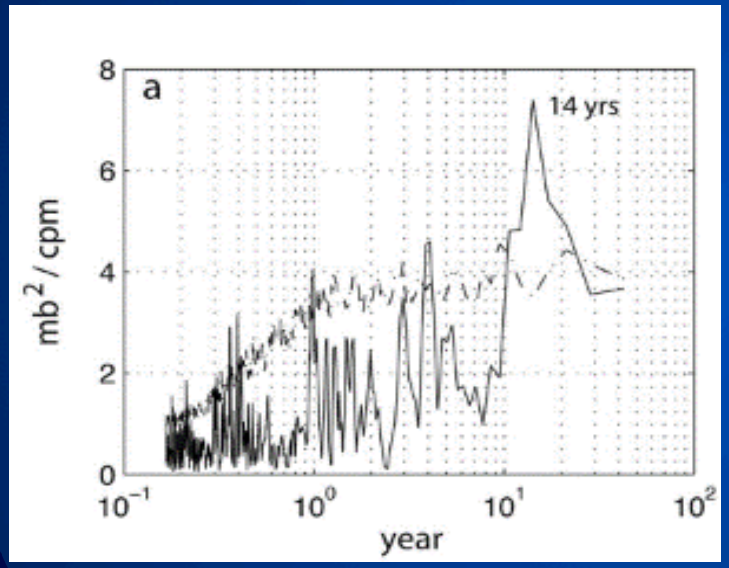
Positive phase: the polar low is strengthened; accompanied by a poleward shift of the westerly jet.

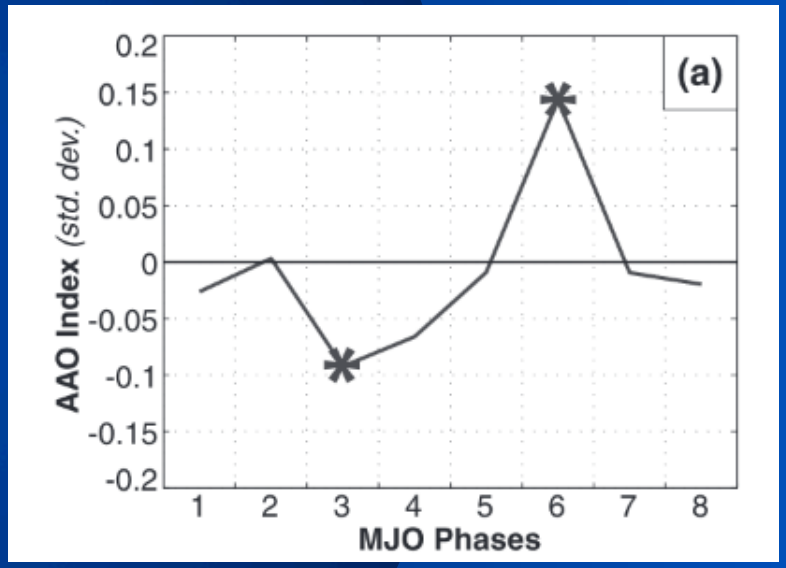
(e.g. Gong and Wang, 1998, 1999; Thompson and Wallance 2000; Li and Wang, 2003; Cai and Watterson, 2002; Gillet et al., 2006; Nan and Li, 2003) .

Significant variability at multiple time scales

Power spectrum density of the SAM index

Intra-seasonal





Yuan and Yonekura 2011

Pohl et al. 2010

During phase 3 of the MJO, the SAM index shows significant negative anomalies, describing on average anomalously high pressure over Antarctica and low pressure over the surrounding ocean

Significant variability at multiple time scales

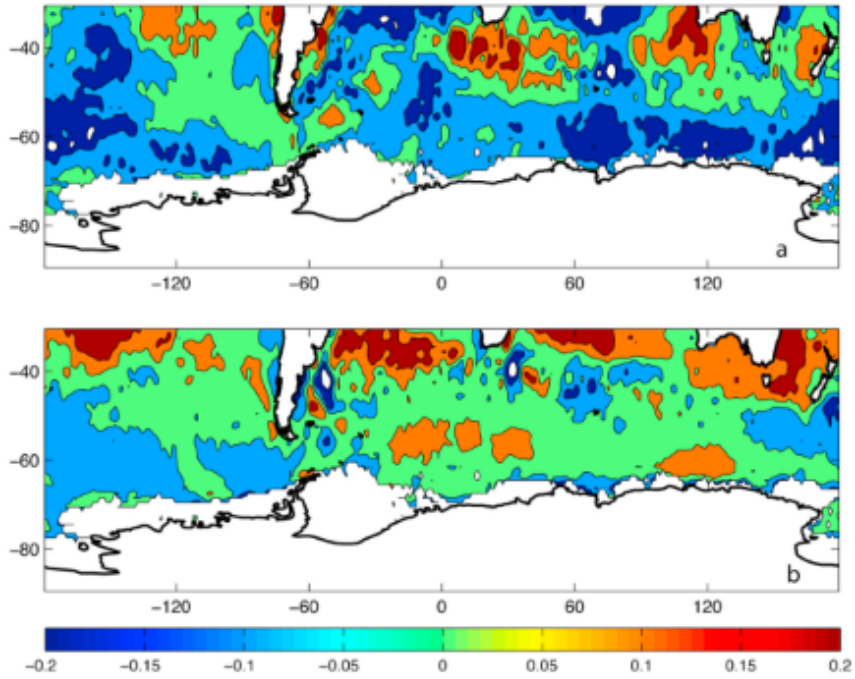


Figure 9. Summer (DJF) composite of SST anomalies for (a) high SAM years (1960–65, 1995–200 and (b) low SAM decade (1970–80).

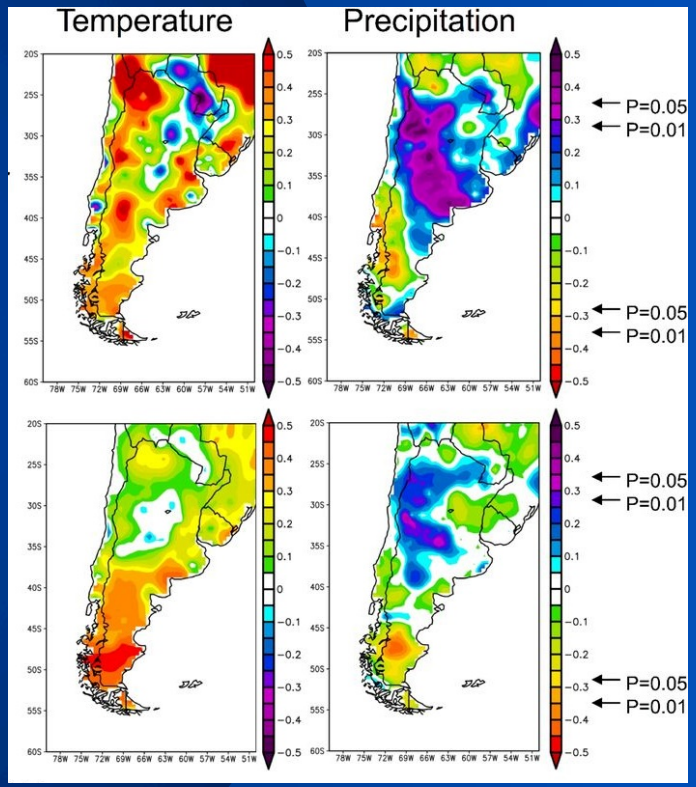
Yuan and Yonekura 2011

Proc Natl Acad Sci U S A. 2017 Sep 5;114(36):9552-9557. doi: 10.1073/pnas.1705168114. Epub 2017 Aug 21.

Southern Annular Mode drives multicentury wildfire activity in southern South America.

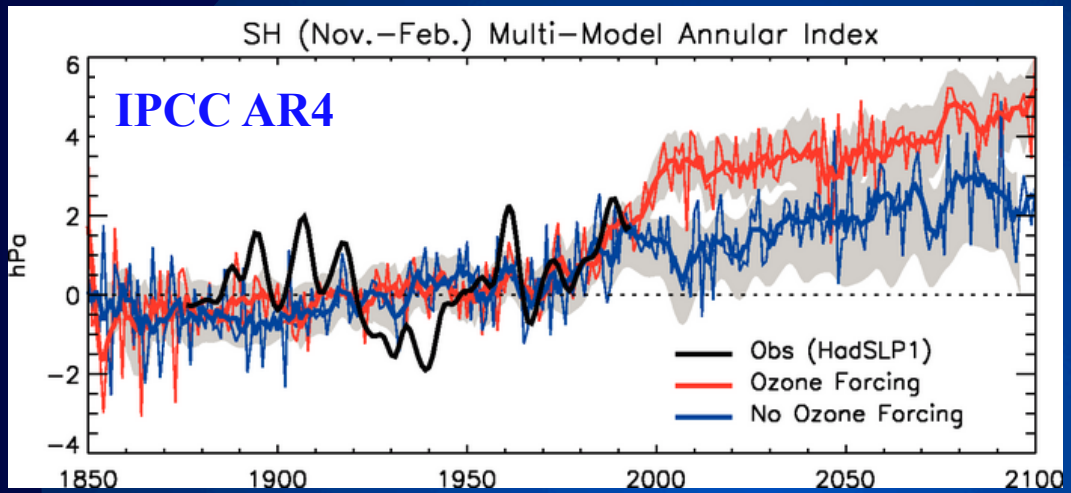
Holz A[1], Paritsis J[2], Mundo IA[3,4], Veblen TT[5], Kitzberger T[2], Williamson GJ[6], Aráoz E[7], Bustos-Schindler C[8], González ME[8,9], Grau HR[7,10], Quezada JM[11].

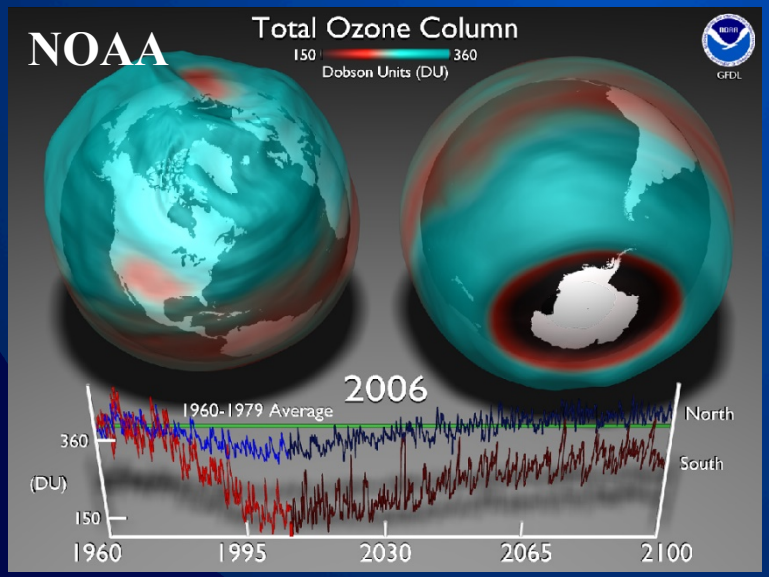
decadal, multidecadal



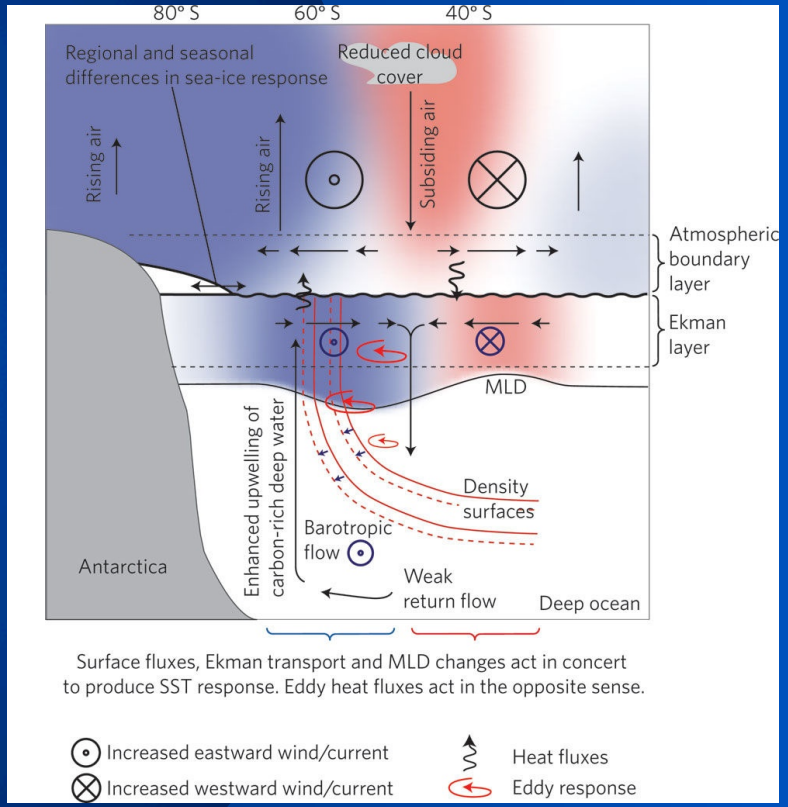
Holz et al. 2017

Significant variability at multiple time scales





Climate change

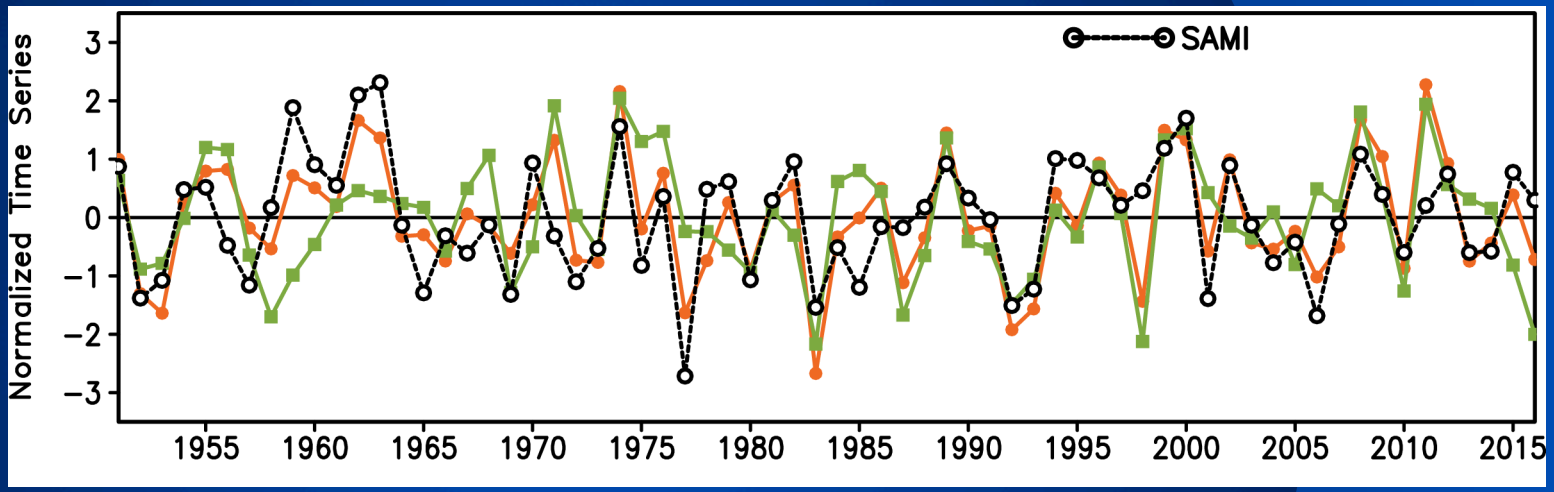


Drivers of Southern Hemisphere climate change

Background

Interannual

SAM's climate impacts

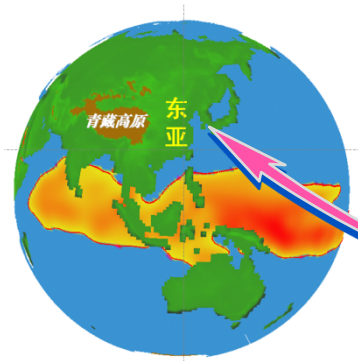


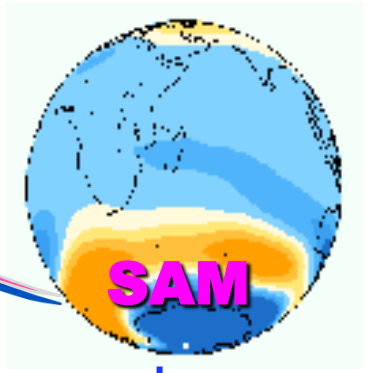
There are large impacts of the SAM on climate not only confined in the SH but also extends to the Northern part ***(e.g. Thompson and Solomon, 2002; Thompson et al., 2011; Kang et al., 2011; Polvani et al., 2011; Son et al., 2009).***

Background

SAM's climate impacts

- promote understanding of different latitudes interactions
- improve dynamical-statistical seasonal prediction





All the seasons indicate boreal seasons

spring SAM & EASM

autumn SAM & EAWM

Mechanism

Mechanism

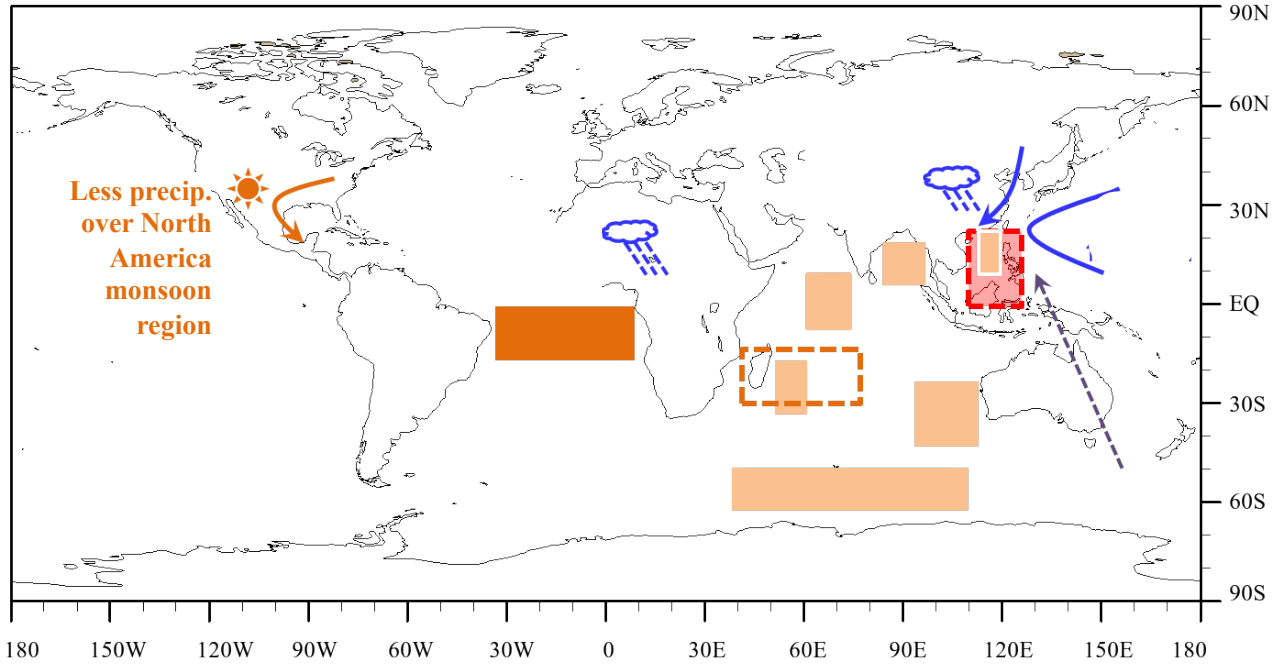
Nan and Li, 2003; Nan et al., 2009

Wu et al., 2009

Prediction model

Influence of SAM on boreal summer climate

A positive phase of boreal spring SAM tends to be followed by a weaker EASM



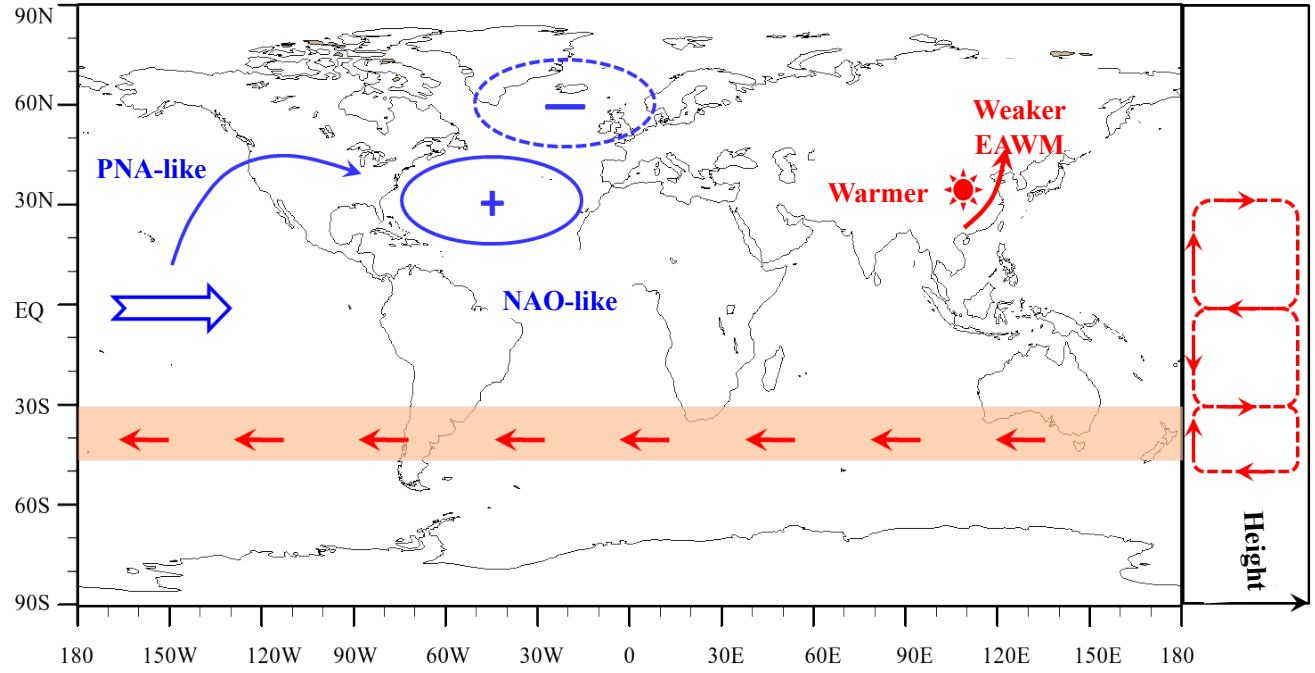
- *Nan S L and Li J P, 2003*
- *Nan S L, Li J P, Yuan X J, and Zhao P, 2009*
- *Xue and Wang, 2004*
- *Wu et al. 2006*
- *Sun et al. 2010*

The mechanism is related to the northward propagation of Indian Ocean SSTA caused by the SAM

Circulation anomalies corresponding to a positive SAM phase

Influence of SAM on boreal winter climate

The East Asian winter monsoon is also modulated by the SAM



Weaker westerlies and warmer SST

Meridional circulation anomalies

Anomalous zonal wind over the TP, further triggers NAO-like and PNA-like variability

- *Wu Z W, Li J P, Wang B, 2009*
- *Song J, Zhou W, Li C Y, Qi L X. 2009*
- *Wu et al., 2015*

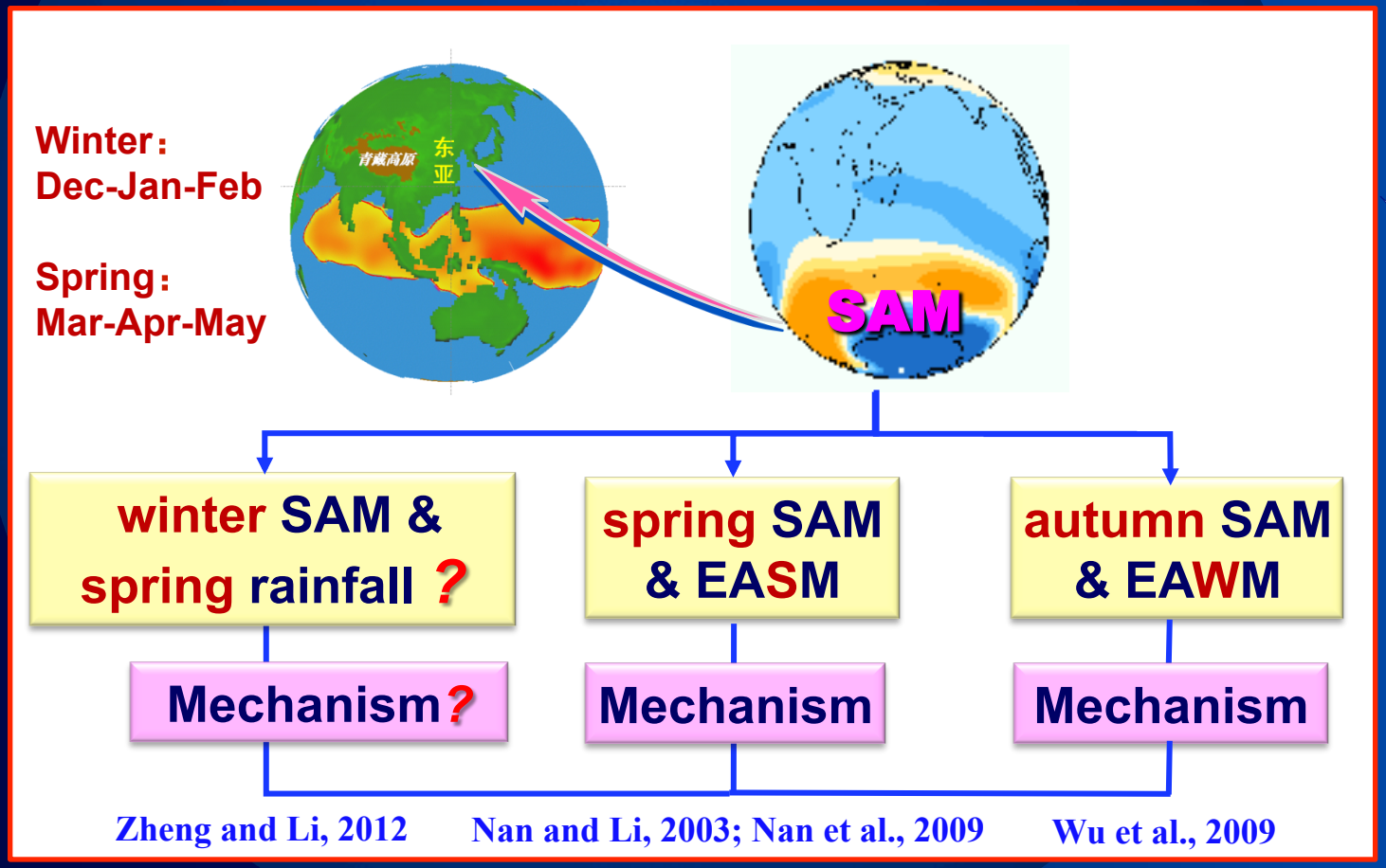
The mechanism is related to responses of the meridional circulation anomalies to the SAM-related SSTA

Circulation anomalies corresponding to a positive SAM phase

Background

SAM's climate impacts

- promote understanding of different latitudes interactions
- improve dynamical-statistical seasonal prediction



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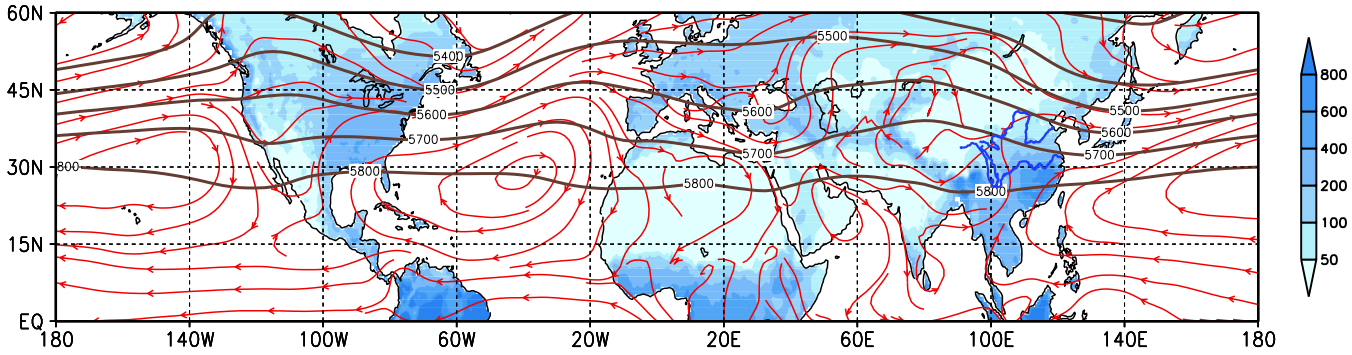
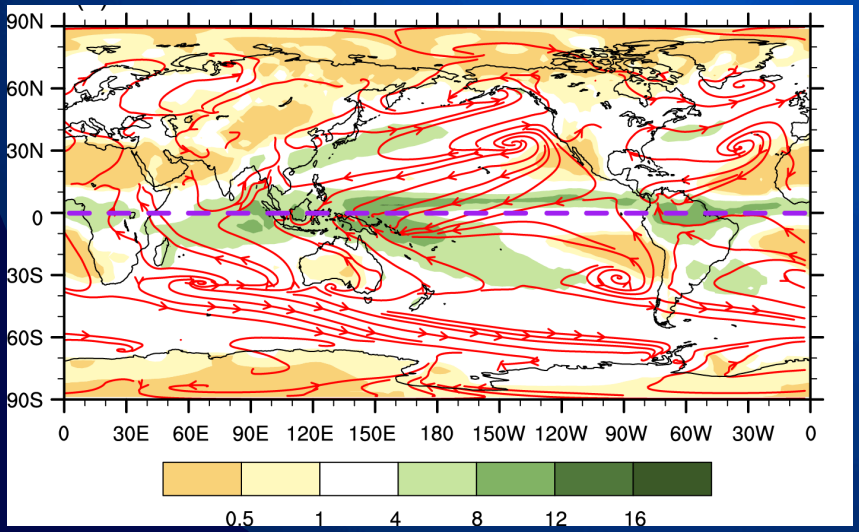
- SOD: Southern Ocean Dipole

Spring climatology | South China



Precipitation, horizontal wind at 850hPa, geopotential height at 500hPa

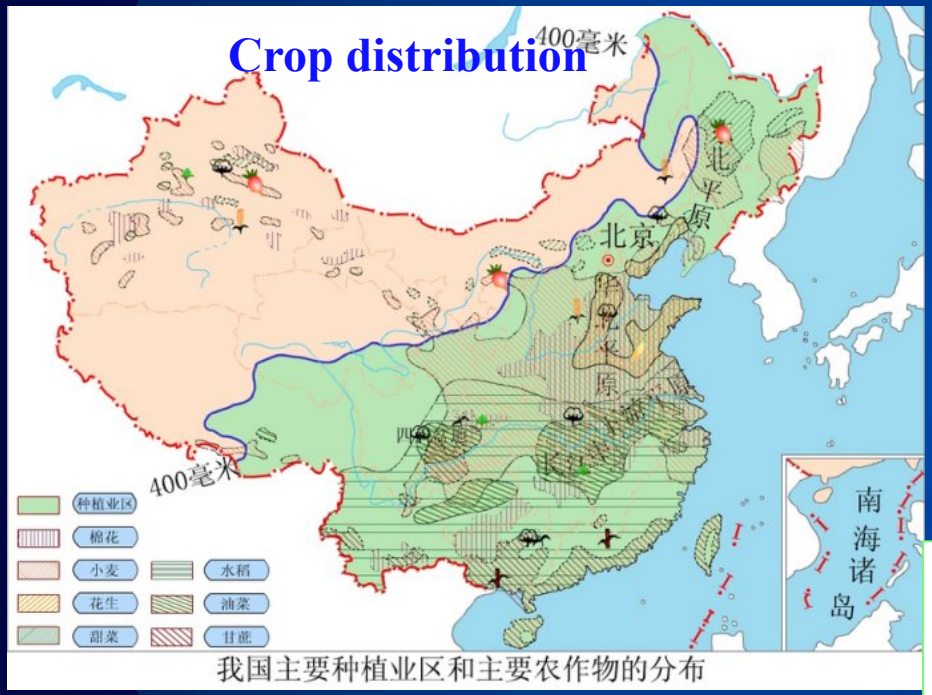


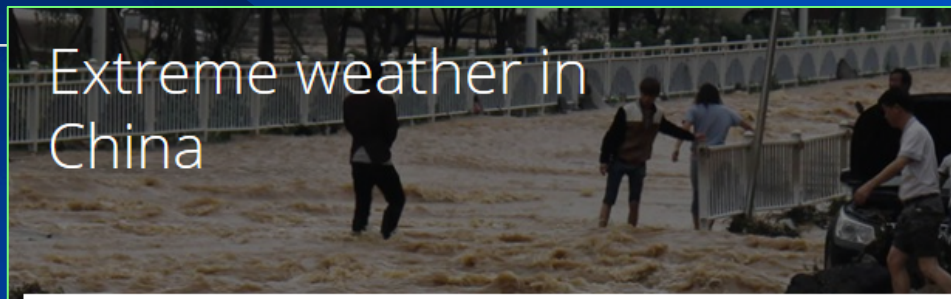
Influenced by the descending branch of the Hadley cell and Ferrel cell

Spring precipitation accounts for ~30% of annual precipitation

Zheng, F., J. P. Li, et al, 2015, *J. Climate*, 28, 6859–6881.

South China is a key region for the growth of a variety of crops



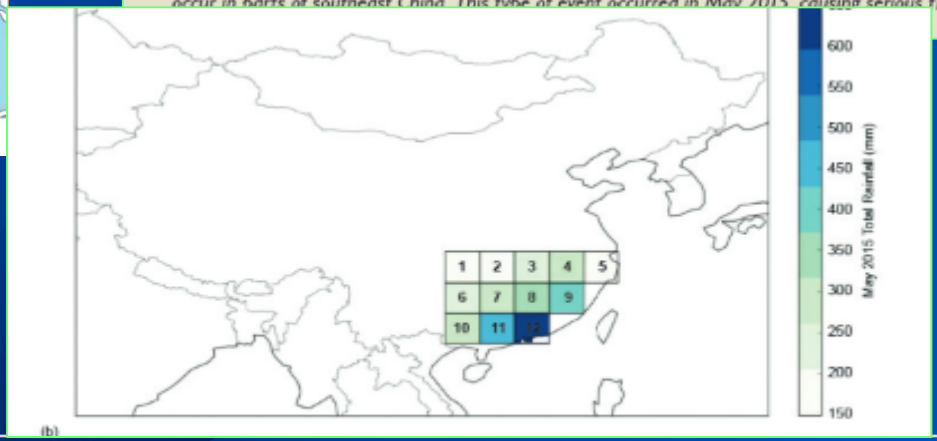


Southern China hit by torrential rain, flooding

18. ATTRIBUTION OF EXTREME RAINFALL IN SOUTHEA
CHINA DURING MAY 2015

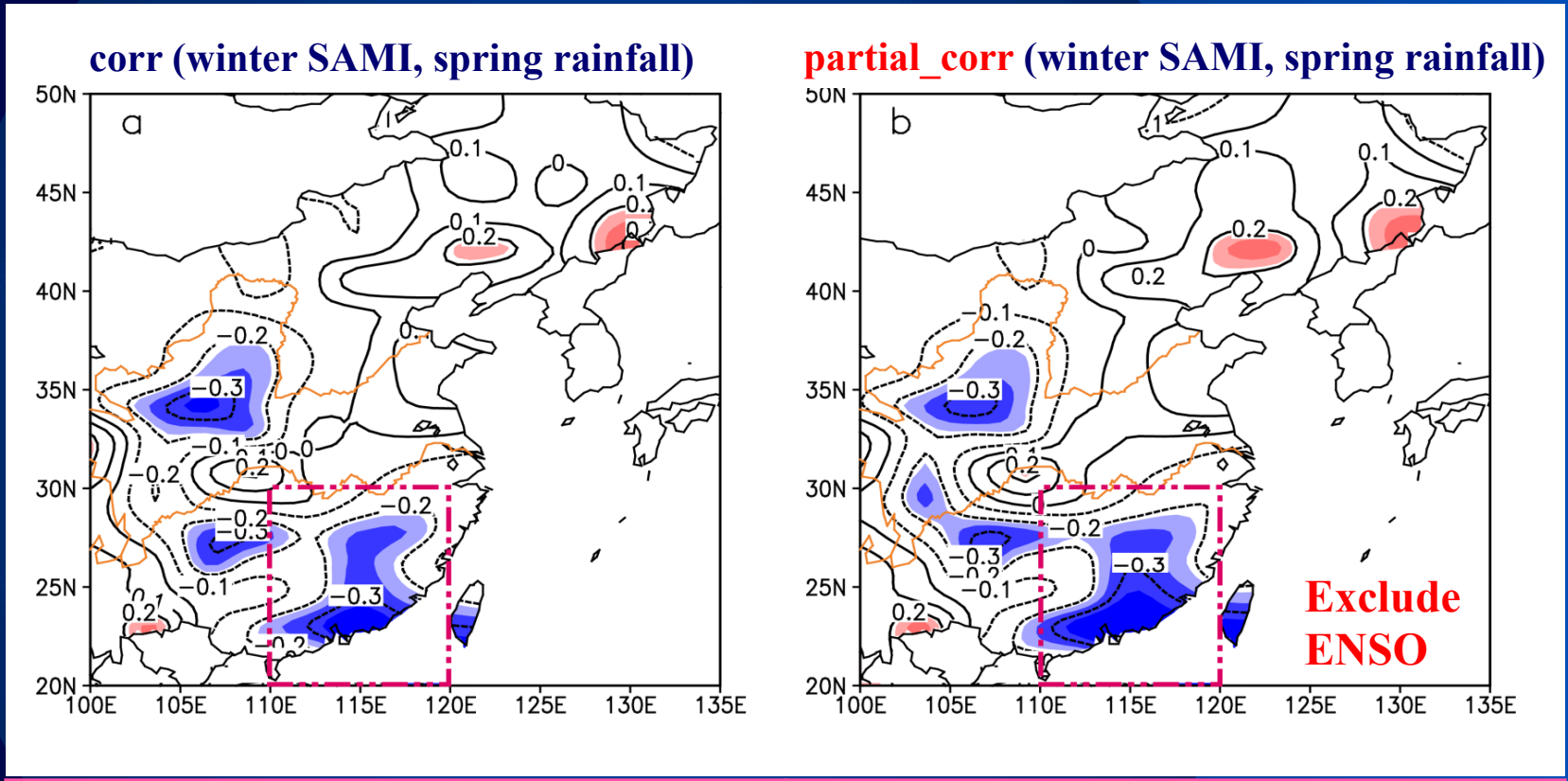
CLAIRE BURKE, PETER STOTT, YING SUN, AND ANDREW CIAVARELLA

Anthropogenic climate change increased the probability that a short-duration, intense rainfall event wo



Precipitation anomalies have great impact on social economy

Significant correlation between winter SAM and SCSP



Positive winter SAM -> Less spring rainfall

Negative winter SAM -> More spring rainfall

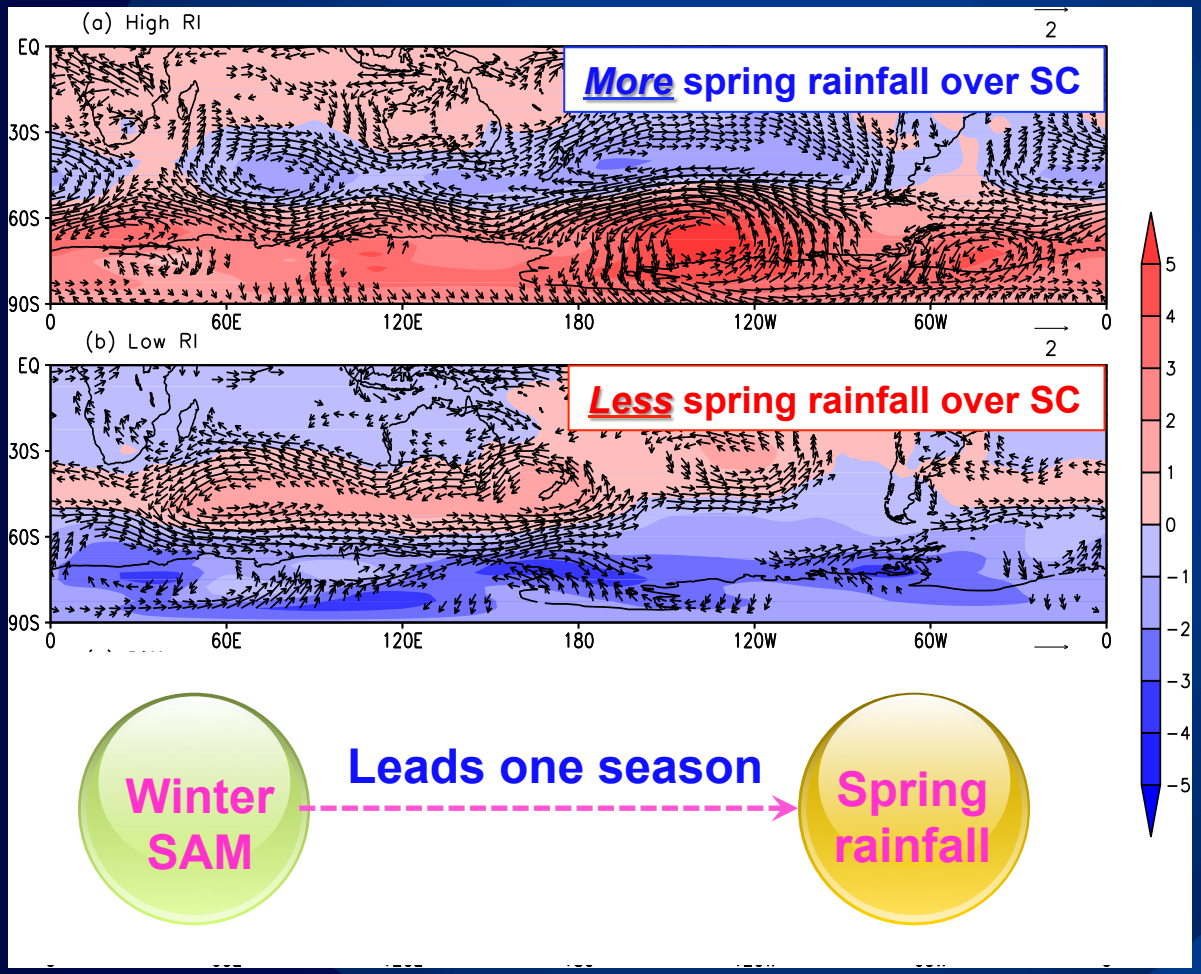
South China Rainfall Index (SCRI)
the normalized time series of the averaged spring rainfall of 11 stations in the red box

Zheng, F., J. P. Li, et al, 2015, *J. Climate*, 28, 6859–6881.

Zheng, F., J. P. Li, et al, 2012, *Chin. J. Geophys*, 55, 3542-3557.

Preceding circulation anomalies associated with SCRI

Composite differences in winter SLP and 850 hPa horizontal wind between high and low spring SCRI



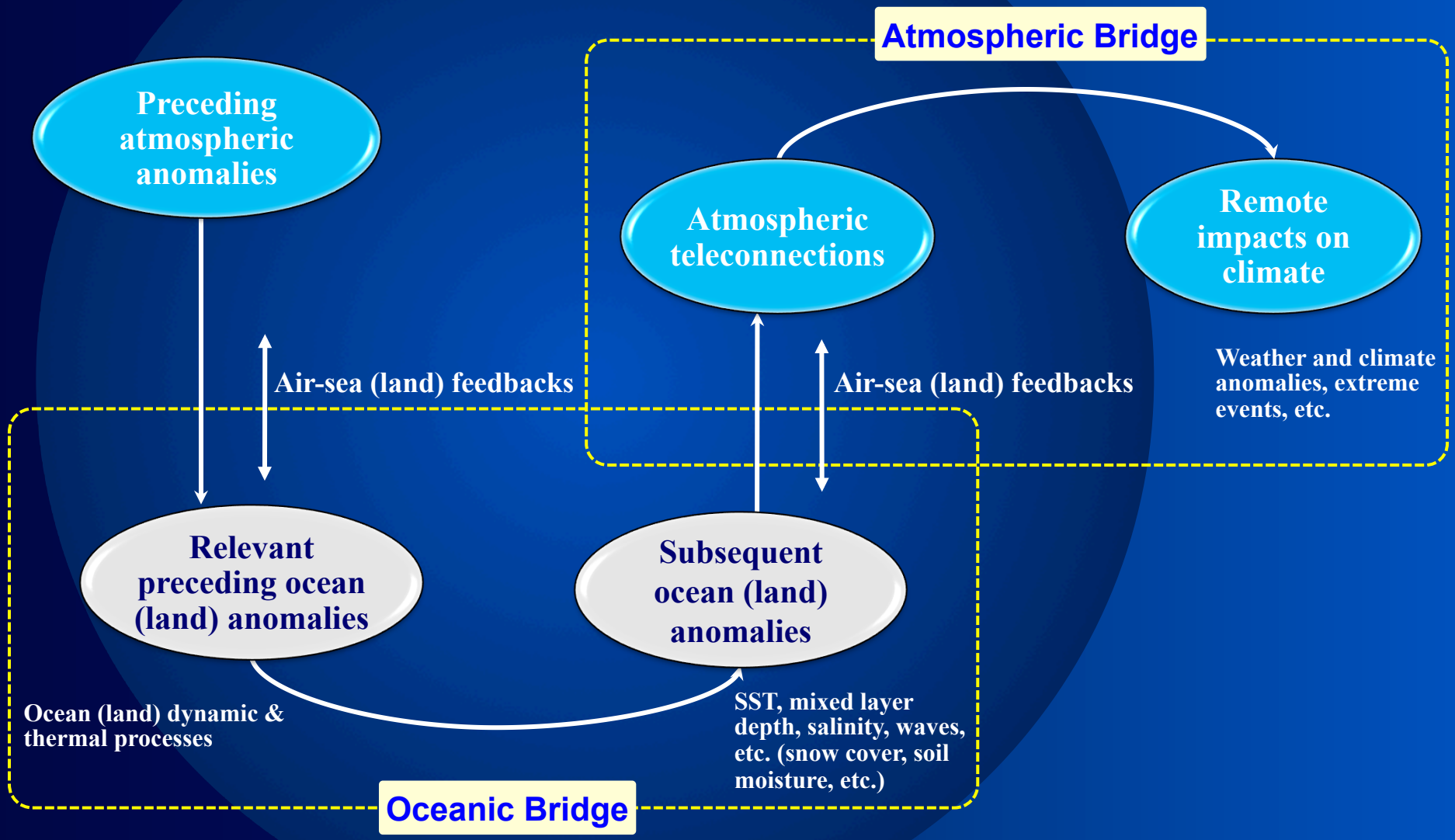
A ***negative*** SAM phase appeared in preceding winter

A ***positive*** SAM phase appeared in preceding winter

Negative correlation (winter SAM, SCSP)

Zheng, F., J. P. Li, et al, 2015, *J. Climate*, 28, 6859–6881.
Zheng, F., J. P. Li, et al, 2012, *Chin. J. Geophys*, 55, 3542-3557.

Ocean's memory for the cross-seasonal influence



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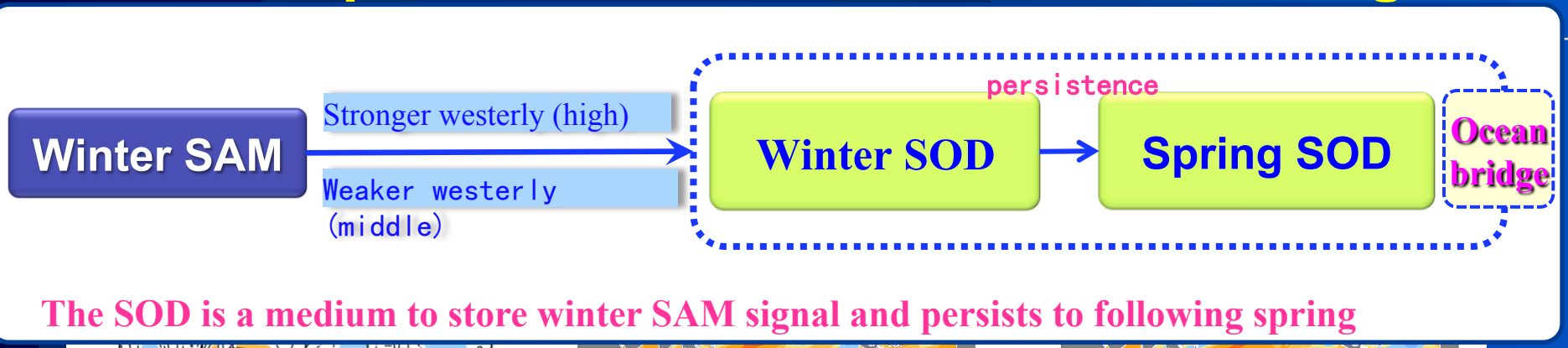
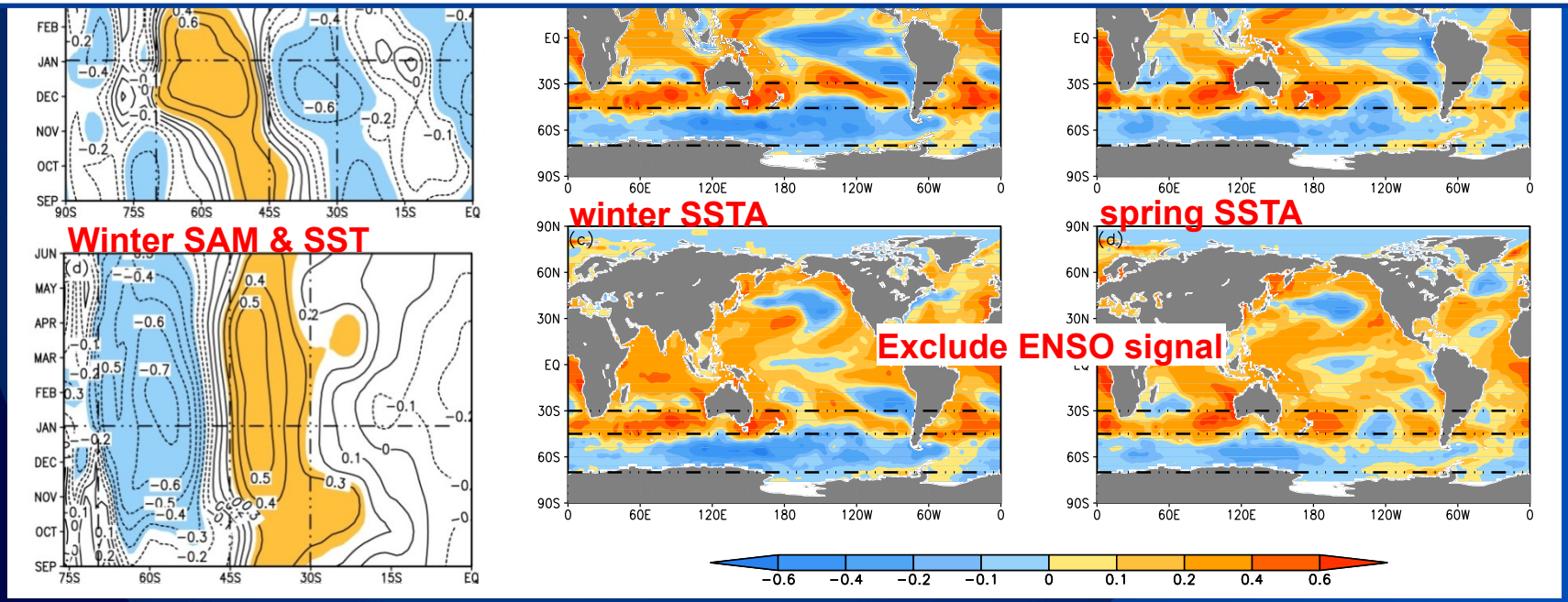
SH extra tropical SST: medium to store SAM signal



The SOD is a medium to store winter SAM signal and persists to following spring

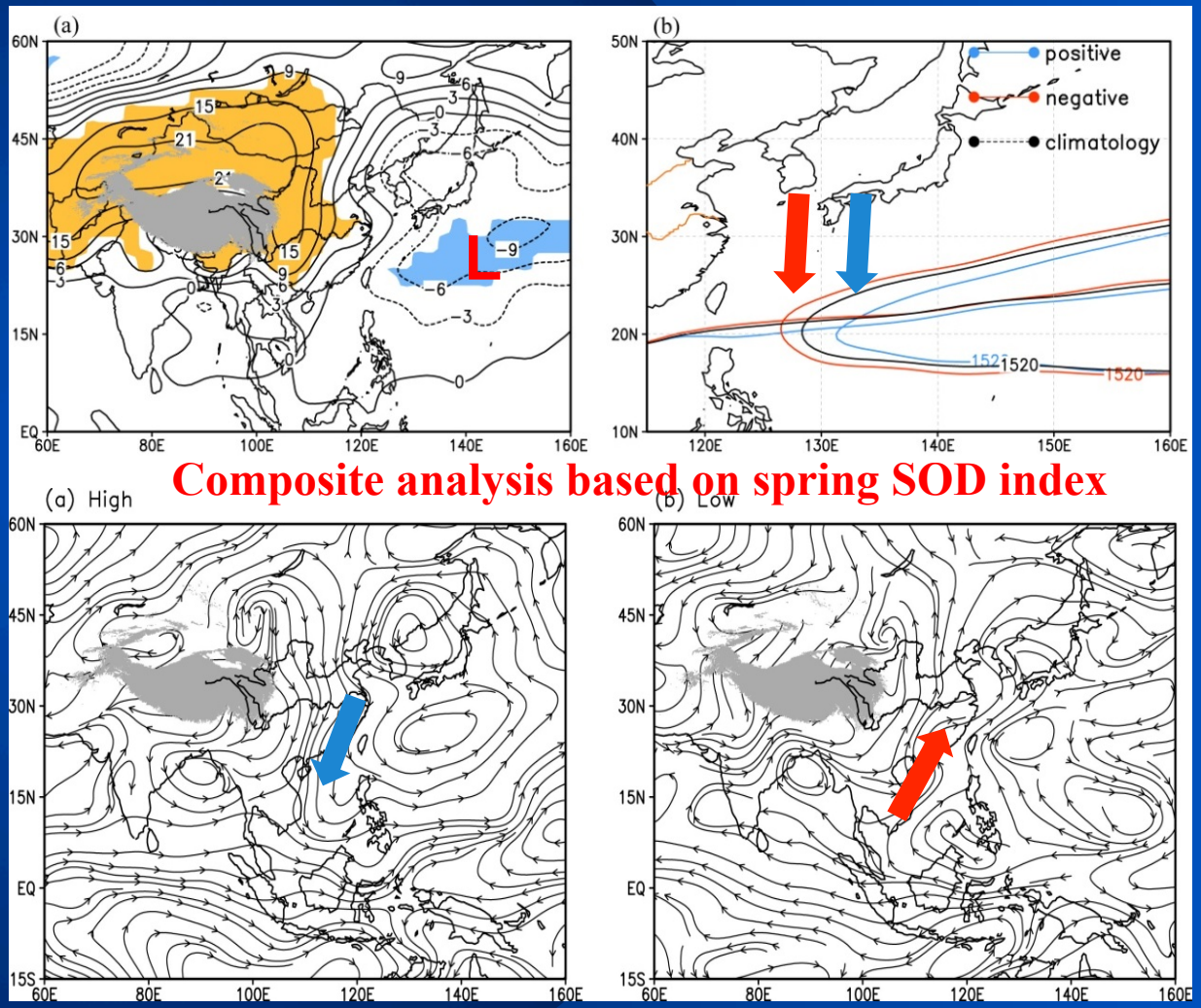


Southern Oceam Dipole (SOD) index: the normalized difference of zonal mean SST between [30º~45ºS] minus [45º~60ºS]

Zheng, F., J. P. Li, et al, 2015, *J. Climate*, 28, 6859–6881.
Zheng, F., J. P. Li, et al, 2012, *Chin. J. Geophys*, 55, 3542-3557.

Circulation anomalies associated with SOD

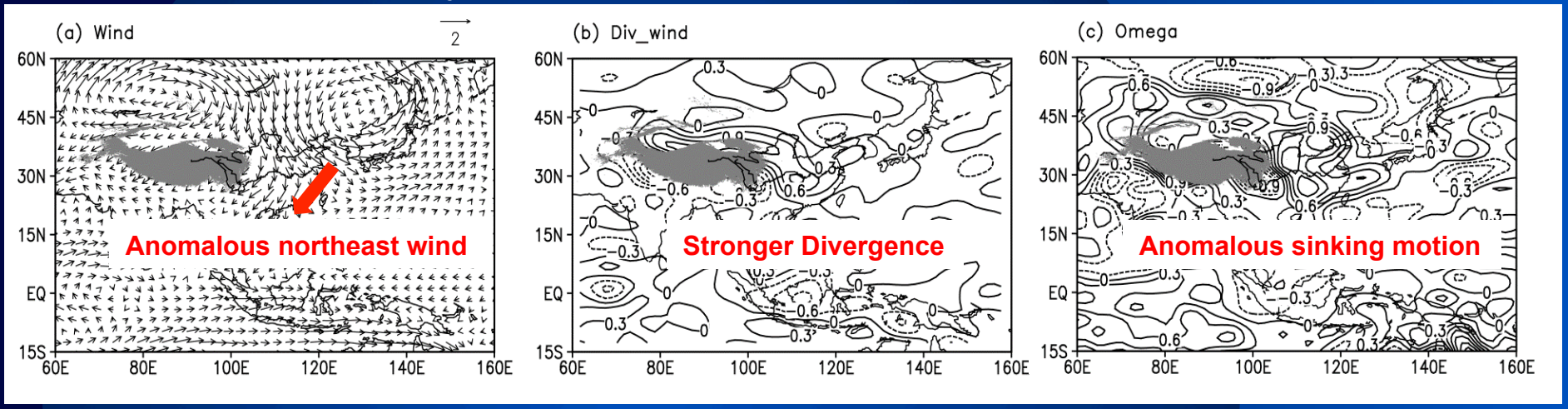
Winter Positive SAM	Winter Negative SAM
Spring Positive SOD	Spring Negative SOD
Subtropical High Retreat Eastward	Subtropical High Extends Westward
Northeast Wind Anomaly	Southwest Wind Anomaly
Less Spring Precipitation	More Spring Precipitation



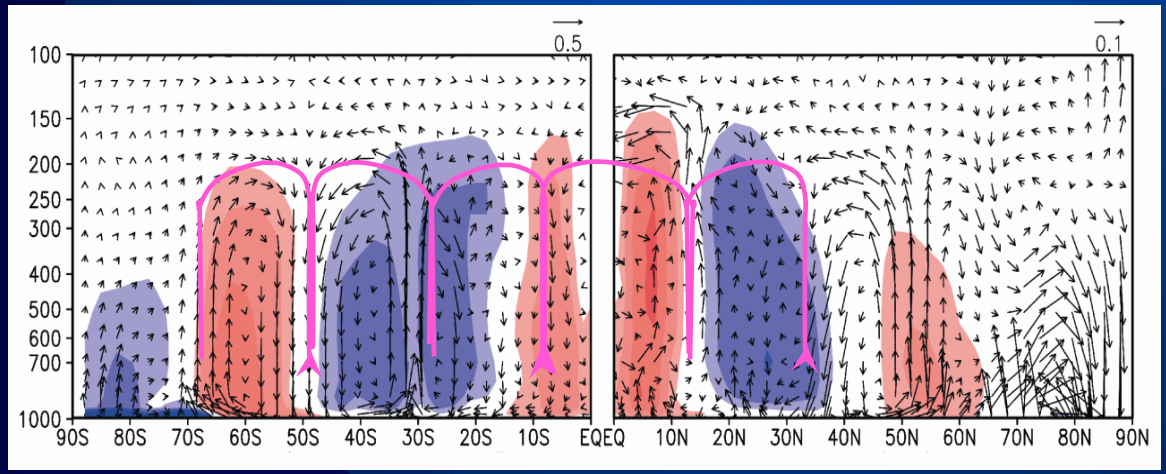
Zheng, F., J. P. Li, et al, 2015, *J. Climate*, 28, 6859–6881.
Zheng, F., J. P. Li, et al, 2012, *Chin. J. Geophys*, 55, 3542-3557.

CAM3 sensitivity experiments: spring SOD SSTA

CAM3: NCAR Community Atmosphere Model, version 3



EXP. A minus Control run

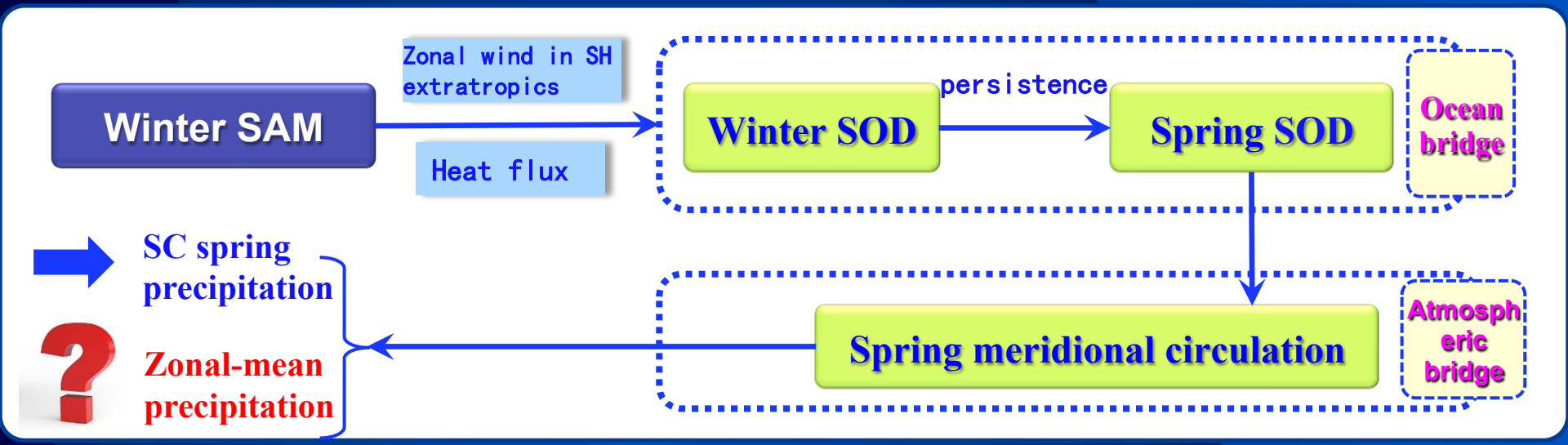


Spring Positive SOD → Subtropical High Retreat Eastward → Northeast Wind Anomaly

Spring Negative SOD → Subtropical High Extends Westward → Southwest Wind Anomaly

Zheng, F., J. P. Li, et al, 2015, *J. Climate*, 28, 6859–6881.
Zheng, F., J. P. Li, et al, 2012, *Chin. J. Geophys*, 55, 3542-3557.

Zonal-mean perspective



- It is well established that ***zonal-mean precipitation*** is closely related with changes in the ***meridional circulation***.
- Considering the influence of spring SOD on spring meridional circulation, ***spring SOD may play a role in modulating zonal-mean precipitation***.

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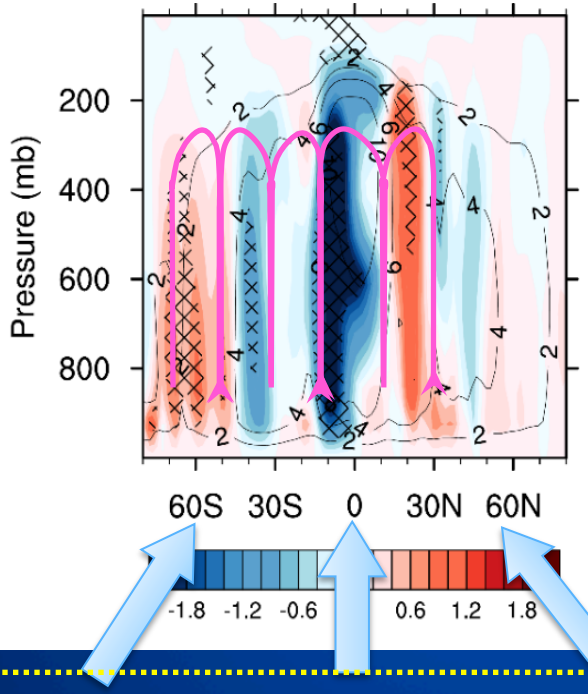
Linkage between spring meridional circulation on winter SAM

Partial regression of spring mass streamfunction on the preceding winter SAM after removing ENSO signal



Regression pattern
Climate noises .vs. significant pattern

Evaluate the significance of regression pattern

××× significant at the 90% confidence level of Student's two-tailed *t*-test

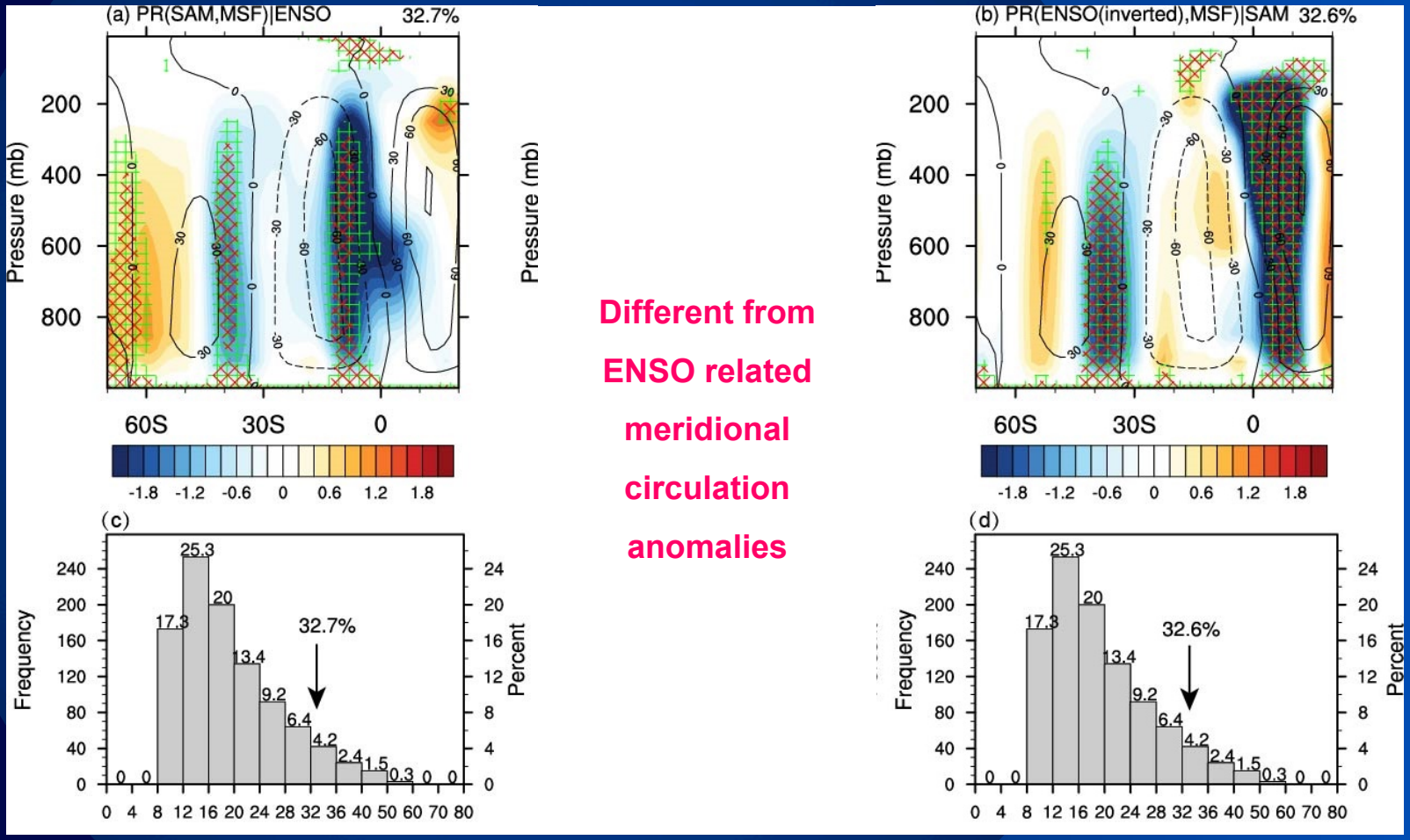
A clockwise cell in SH high latitudes and a counterclockwise cell in middle latitudes.

A counter-clockwise cell in the tropics

A clockwise cell in the NH subtropics

Anomalous clockwise and counterclockwise cells occur alternately from the SH middle latitudes to NH subtropics.

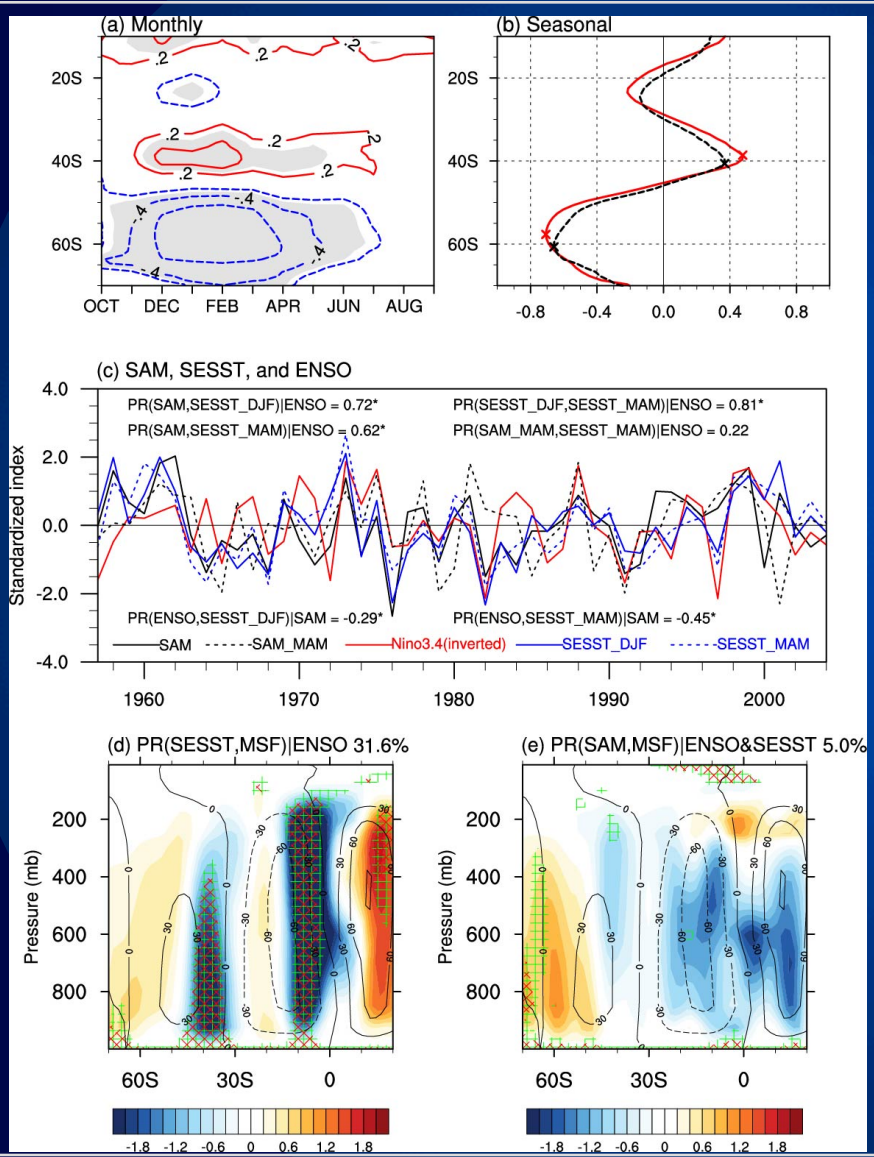
Field significance test based on 1000 Monte Carlo simulations



Different from ENSO related meridional circulation anomalies

Details about the field significance test (Livezey and Chen 1983)

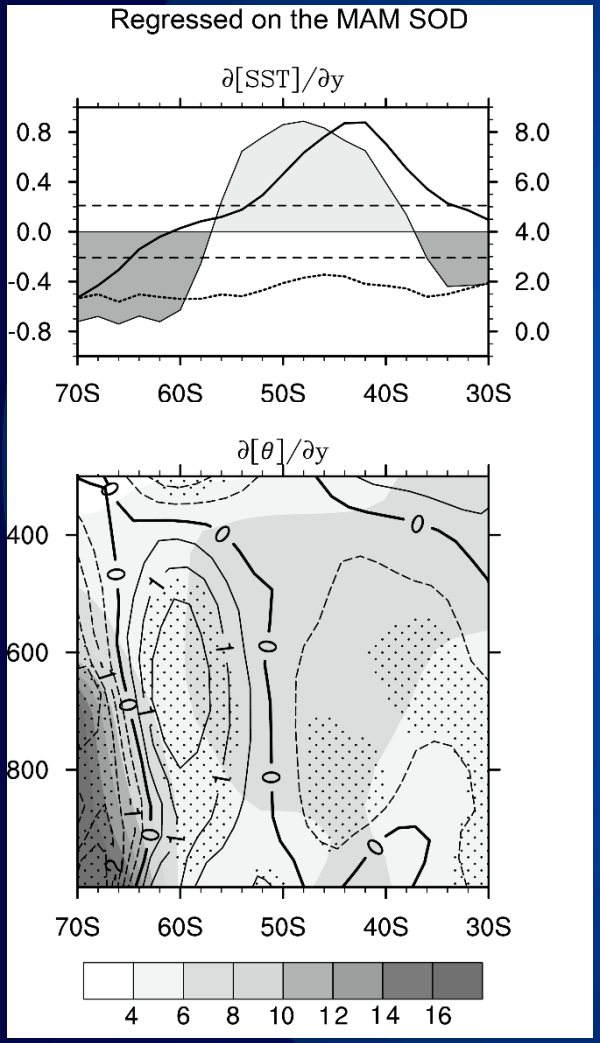
The importance of the SOD in the cross-seasonal influence of the winter SAM on spring meridional circulation



- Partial regression of spring mass streamfunction on the winter SAM after removing SOD
- Significant relationship almost disapper

Zheng et al. 2017, IJOC

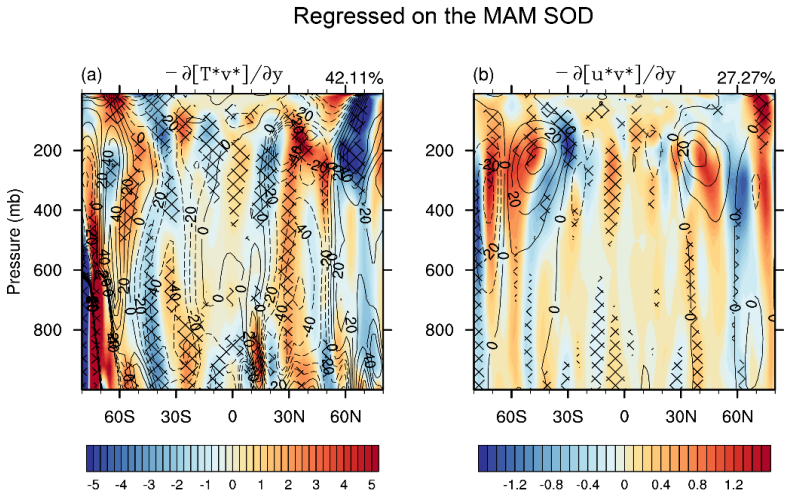
Mechanism ①: Changes in baroclinicity

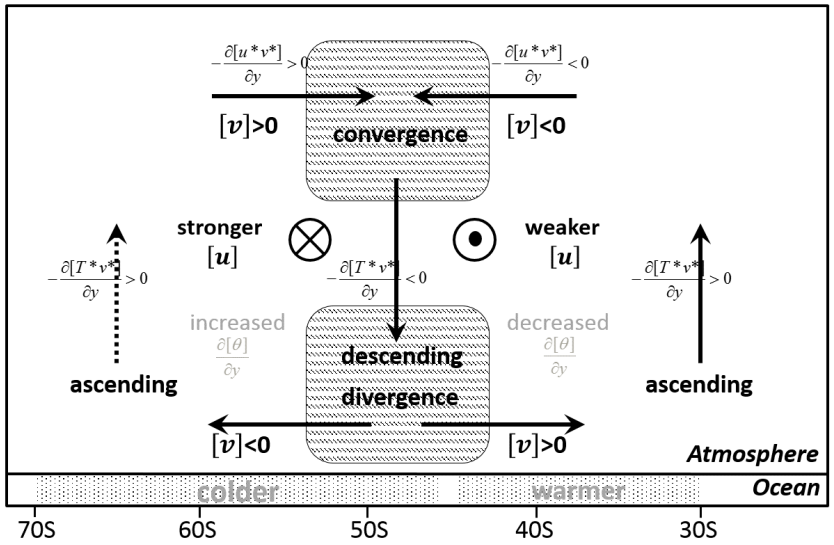


- The spring **SOD activity** is accompanied by **changes in meridional gradient of SST**. SST gradient is enhanced between 57°S and 37°S but reduced south of that region.

- These SST gradient anomalies have the potential to further **modify atmospheric baroclinicity**. Baroclinicity increases (decreases) south (north) of 50°S.

Mechanism ②: Changes in eddy momentum flux





Changes in baroclinicity may trigger wave adjustments. A framework based on momentum and heat budget analysis is built to explain the response of spring meridional circulation to spring SOD.

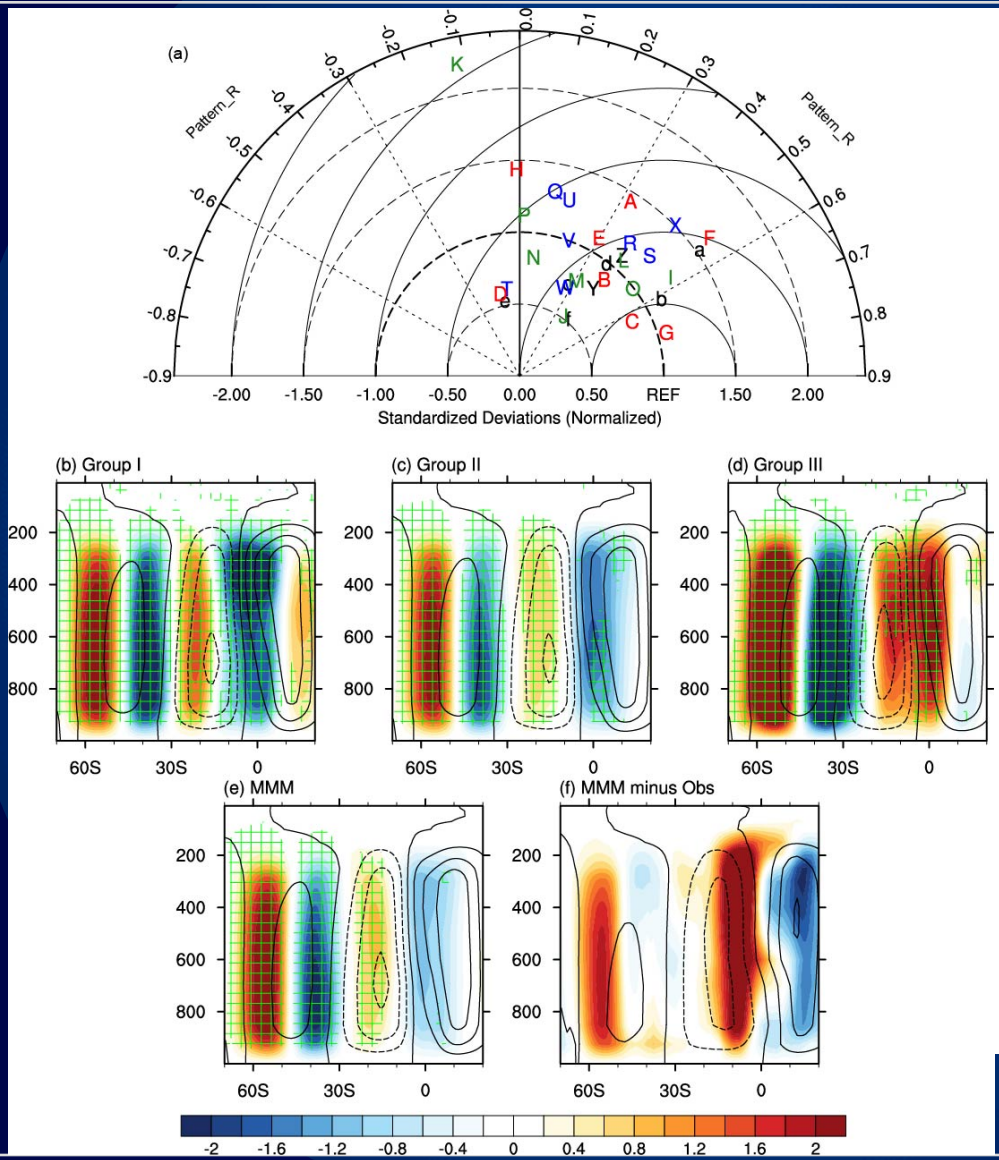
$$[v] \approx \frac{1}{f}\frac{\partial[u^*v^*]}{\partial y}$$

$$[w] \approx -\frac{R}{N^2 H}\frac{\partial[T^*v^*]}{\partial y}$$

- Zonal-mean momentum equation
- Zonal-mean heat equation

Zheng, F., J. P. Li, et al, 2015, *J. Climate*, 28, 6859–6881.
Zheng, F., J. P. Li, et al, 2012, *Chin. J. Geophys*, 55, 3542-3557.

Regression of spring meridional circulation on spring SOD (CMIP5 historical simulations)



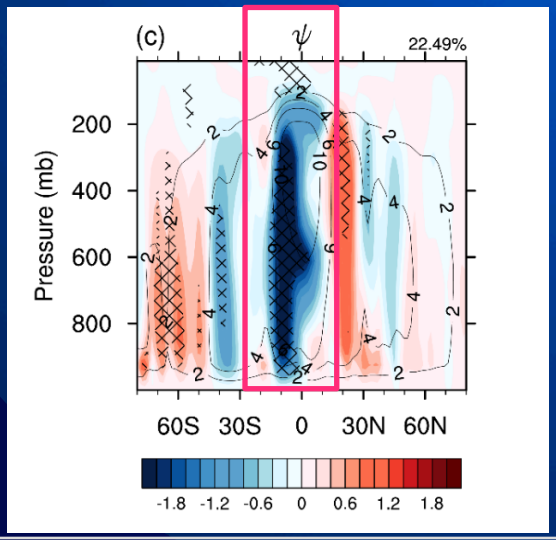
A	ACCESS1-0
B	ACCESS1-3
C	BCC-CSM1-1
D	BCC-CSM1-1-M
E	BNU-ESM
F	CanESM2
G	CMCC-CM
H	CMCC-CMS
I	CNRM-CM5
J	CSIRO-Mk3-6-0
K	FGOALS-s2
L	GFDL-CM3
M	GFDL-ESM2G
N	GFDL-ESM2M
O	GISS-E2-H
P	GISS-E2-H-CC
Q	GISS-E2-R
R	HadCM3
S	HadGEM2-AO
T	INMCM4
U	IPSL-CM5A-LR
V	IPSL-CM5A-MR
W	MIROC-ESM
X	MIROC-ESM-CHEM
Y	MIROC5
Z	MPI-ESM-LR
a	MPI-ESM-MR
b	MPI-ESM-P
c	MRI-CGCM3
d	MRI-ESM1
e	NorESM1-M
f	NorESM1-ME

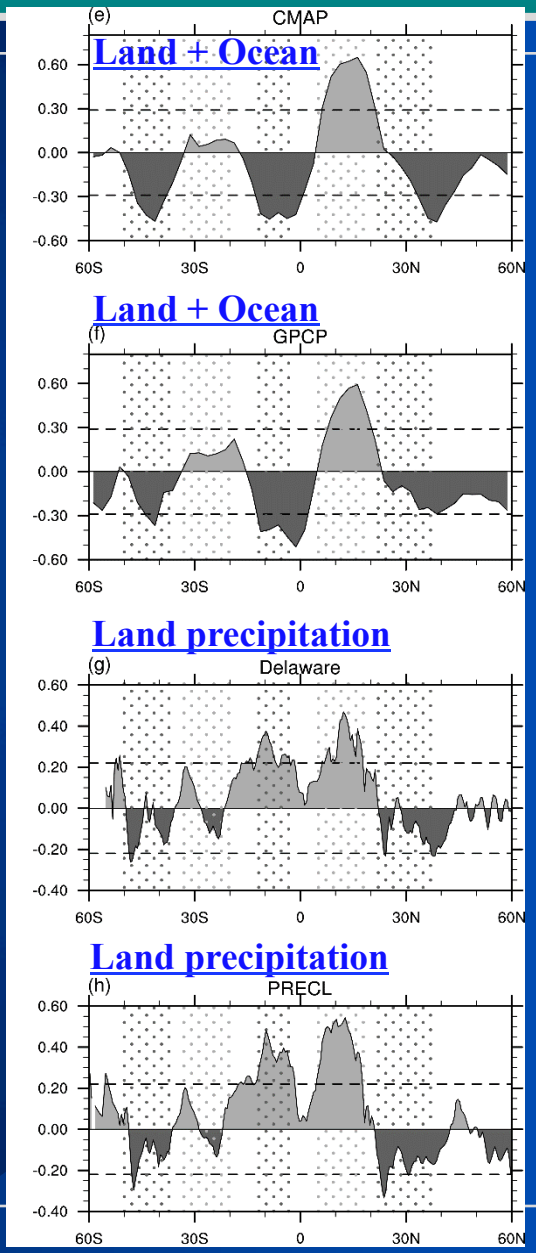
Zheng et al. 2017, IJOC

Responses of spring zonal-mean precipitation to the DJF SAM

Because of the responses of spring meridional circulation to the winter SAM, the spring zonal-mean precipitation is also related to the DJF SAM.

Less and more precipitation occur alternately between the SH middle latitudes and NH subtropics.

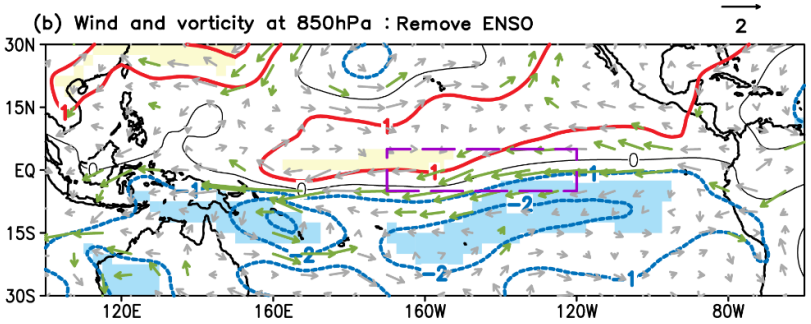




Zheng, F., J. P. Li, et al, 2015, *J. Climate*, 28, 6859–6881.

Influence of the boreal winter SAM on spring tropical Pacific SST

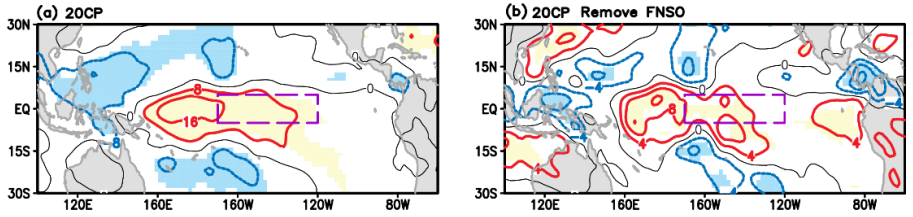
Composite difference of spring wind at 850hPa based on the winter SAM



The typical ENSO years have been excluded before the composite analysis

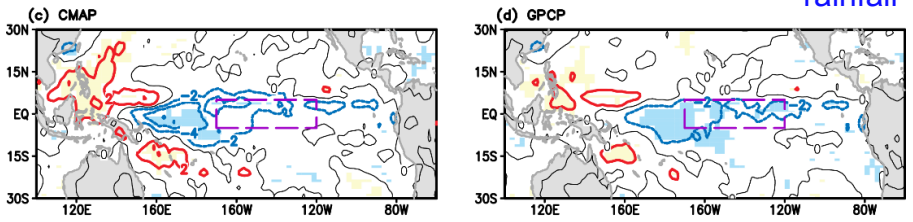
Composite Diff. of MAM OLR based on the DJF SAM

OLR

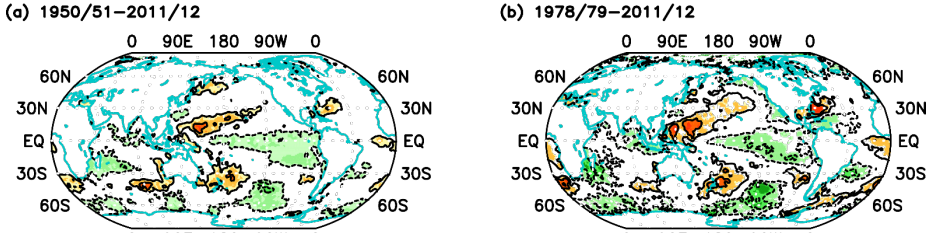


Composite Diff. of MAM Precipitation based on the DJF SAM

rainfall



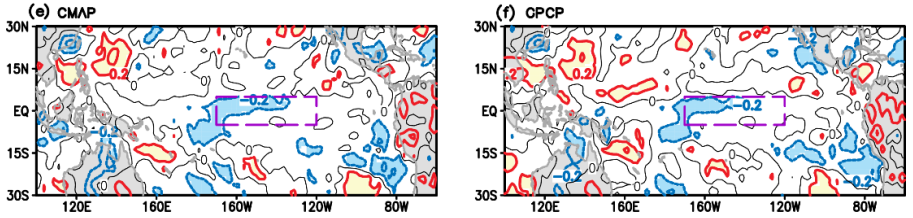
HadISST: Corr–dt (DJF SAM, MAM SST)



A significant negative correlation between the winter SAM and spring central tropical Pacific SST

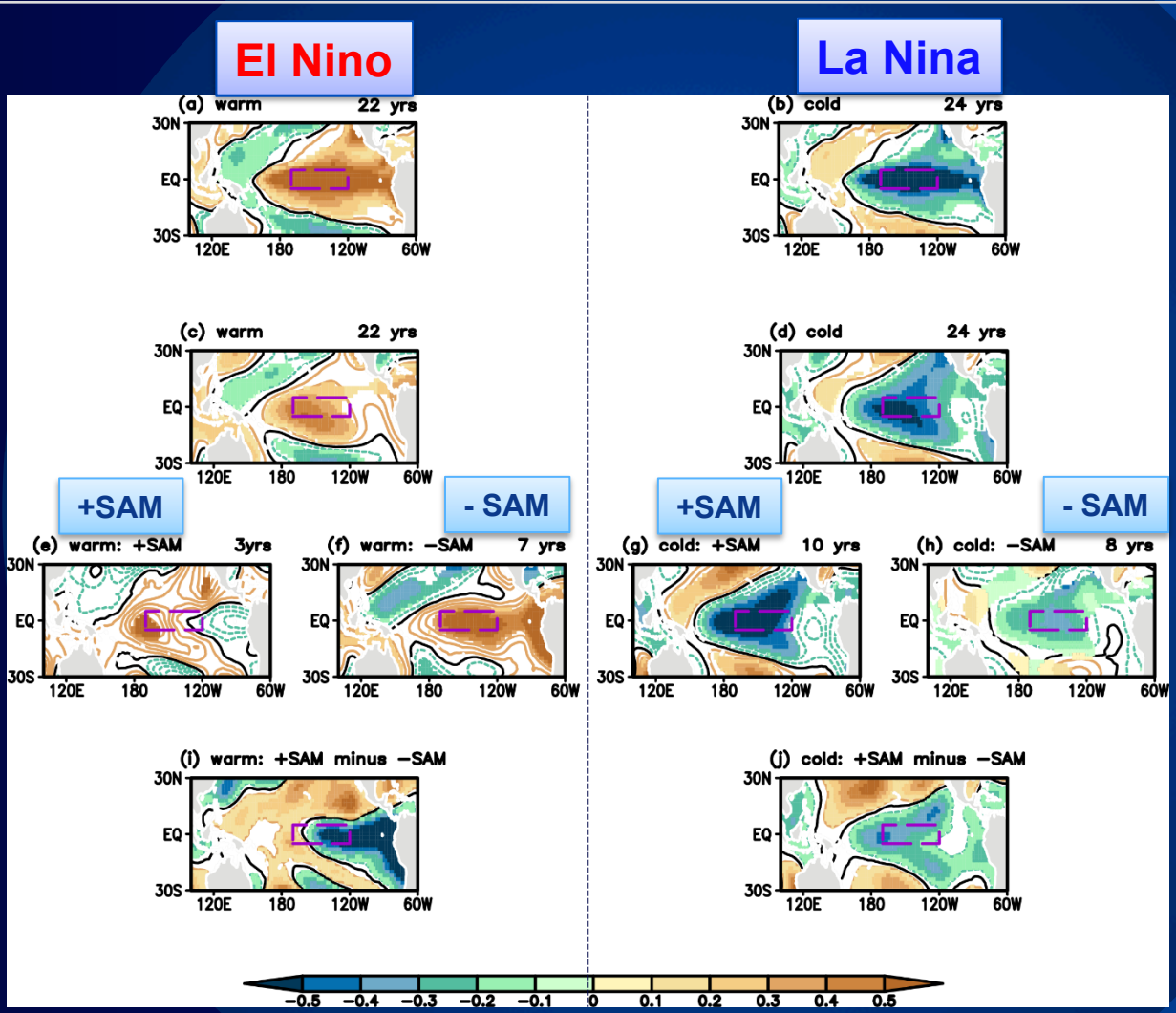
Partial Corr. between MAM Precipitation and the DJF SAM

rainfall



The linkage between the winter SAM and spring central tropical pacific SST

Composite analysis



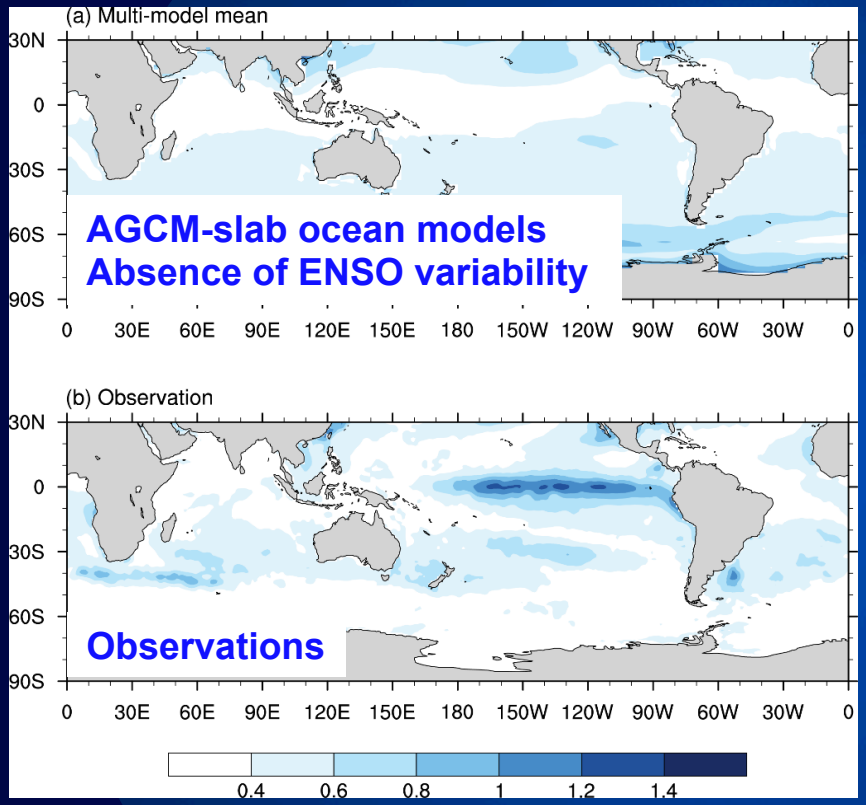
A significant negative correlation between the winter SAM and spring central tropical Pacific SST

El Niño-like SSTA over the central Pacific in spring corresponding to +SAM is cooler than that corresponding to -SAM

La Niña-like SSTA in spring corresponding to +SAM is cooler than that corresponding -SAM

Zheng, F., J. P. Li, et al, 2017, *Adv. Atmos. Sci.*

CMIP3 AGCM-slab ocean models

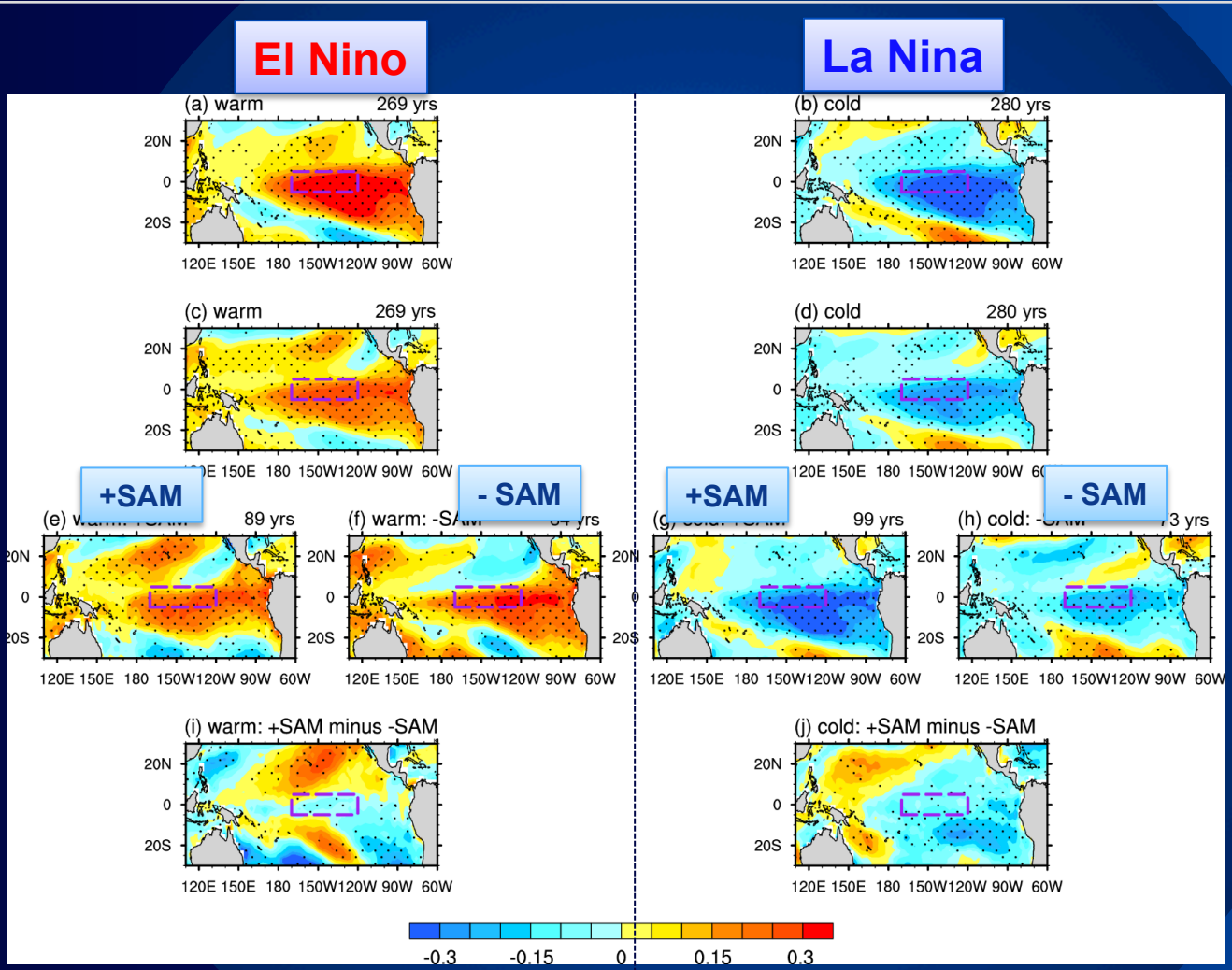


Model names	Simulation length (yrs.)	Resolution	
		nLon×nLat	nLev
cccma_cgcm3_1_t47	30	96 × 48	17
cccma_cgcm3_1_t63	30	128 × 64	17
csiro_mk3_0	60	192 × 96	17
gfdl_cm2_0	50	144 × 90	17
gfdl_cm2_1	100	144 × 90	17
giss_model_e_r	120	72 × 46	17
inmcm3_0	60	72 × 45	17
miroc3_2_hires	20	320 × 160	17
miroc3_2_medres	60	128 × 64	17
mpi_echam5	100	192 × 96	16
mri_cgcm2_3_2a	150	128 × 64	17
ncar_ccsm3_0	51	256 × 128	17
ukmo_hadgem1	70	192 × 145	16

SST variability is determined by the thermodynamic equation, without ocean dynamical processes

A convenient way to remove the climatic influence of ENSO and investigate the role extratropical factors in modulating tropical Pacific SST

Composite analysis (CMIP3 AGCM-slab ocean models)



Although the variances of spring tropical Pacific SST explained by the winter SAM are smaller than those by the winter ENSO, influences of the winter SAM on spring tropical Pacific SST may overlay on the influence of winter ENSO.

The negative correlation between the winter SAM and spring tropical Pacific SST reflects the possible influence of the winter SAM on the amplitude of ENSO.

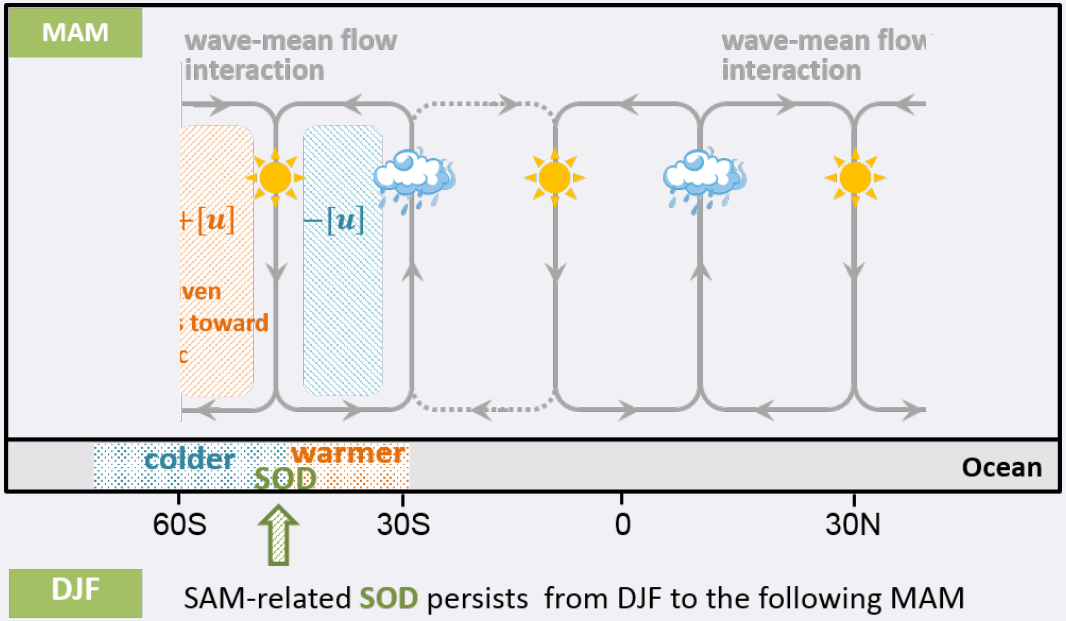
Outline

1. Background
2. Linkage between winter SAM & SCSP
3. Mechanism for the impact of winter SAM on SCSP
4. Winter SAM & spring zonal-mean precipitation
5. Summary and highlight

- SCSP: South China Spring Precipitation
- SOD: Southern Ocean Dipole

Highlight-1

SAM's climate impacts

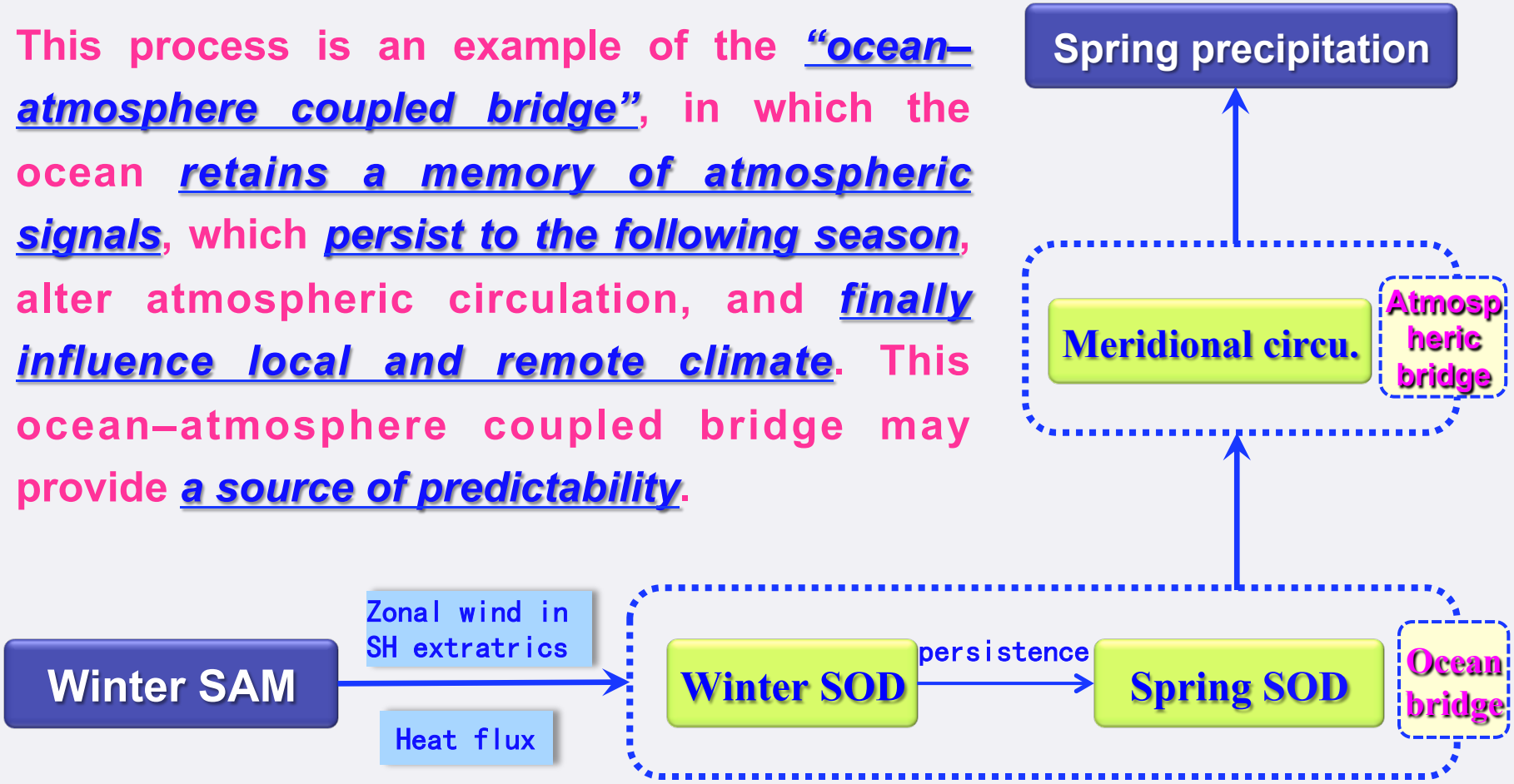


This study provides ***new evidence for the influence of the extratropics on the tropics and beyond***. Although the SAM itself is mainly confined to the SH extratropics, its influence on zonal-mean circulation may reach the tropics and even the NH.

Highlight-2

SAM's climate impacts

This process is an example of the ***"ocean–atmosphere coupled bridge"***, in which the ocean ***retains a memory of atmospheric signals***, which ***persist to the following season***, alter atmospheric circulation, and ***finally influence local and remote climate***. This ocean–atmosphere coupled bridge may provide ***a source of predictability***.

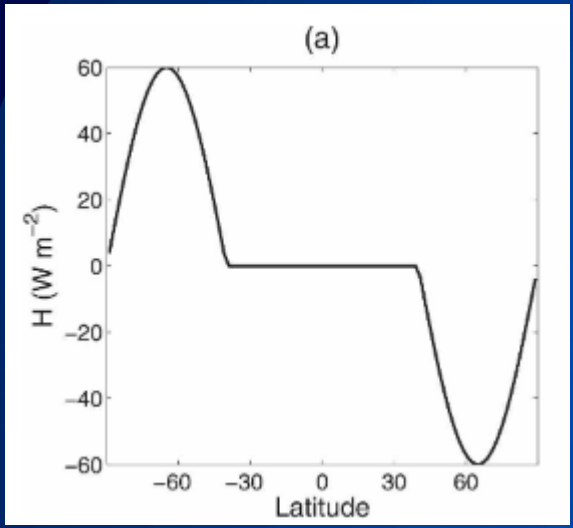


Thank you for your attention!

Welcome for comments and suggestions!

1. Zheng, F., J. Li, L. Wang, F. Xie, X. F. Li, 2015: Cross-Seasonal Influence of the December–February Southern Hemisphere Annular Mode on March–May Meridional Circulation and Precipitation. *J. Climate*, **28**, 6859–6881.
2. Zheng, F., J. P. Li, 2012: The impacts of the preceding winter SAM on the spring south China rainfall and its mechanism. *Chinese J. Geophys.*, **55**(11), 3542-3557.
3. Zheng et al. 2017: Cross-Seasonal Influence of the SAM on Southern Hemisphere Extratropical SST and its Relationship with Meridional Circulation in CMIP5 models. *Int. J. Climatol.*
4. Zheng et al., 2017: Influence of the Preceding Austral Summer Southern Hemisphere Annular Mode on the Amplitude of El Niño–Southern Oscillation Decaying. *AAS.*

The Response of the ITCZ to Extratropical Thermal Forcing: Idealized Slab-Ocean Experiments with a GCM



Kang et al. 2008

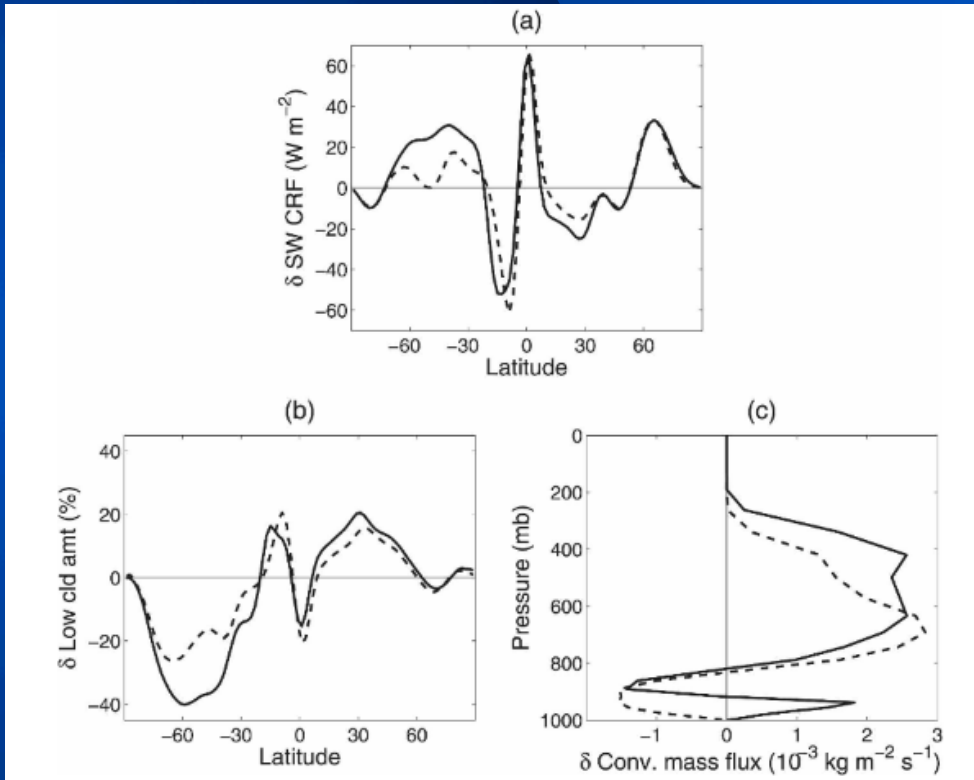


FIG. 13. (a) The change in shortwave component of cloud forcing in W m^{-2}. (b) The change in low-cloud amount (%). (c) The change in convective mass flux averaged over 90° and 30°S in 10^{-3} kg m^{-2} s^{-1}. All plots are for the case A = 60 W m^{-2}. Lines as in Fig. 8.