State Key Laboratory of Numerical Modelling for Atmospheric Sciences
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Impacts of ENSO on the East Asian-western North Pacific monsoon

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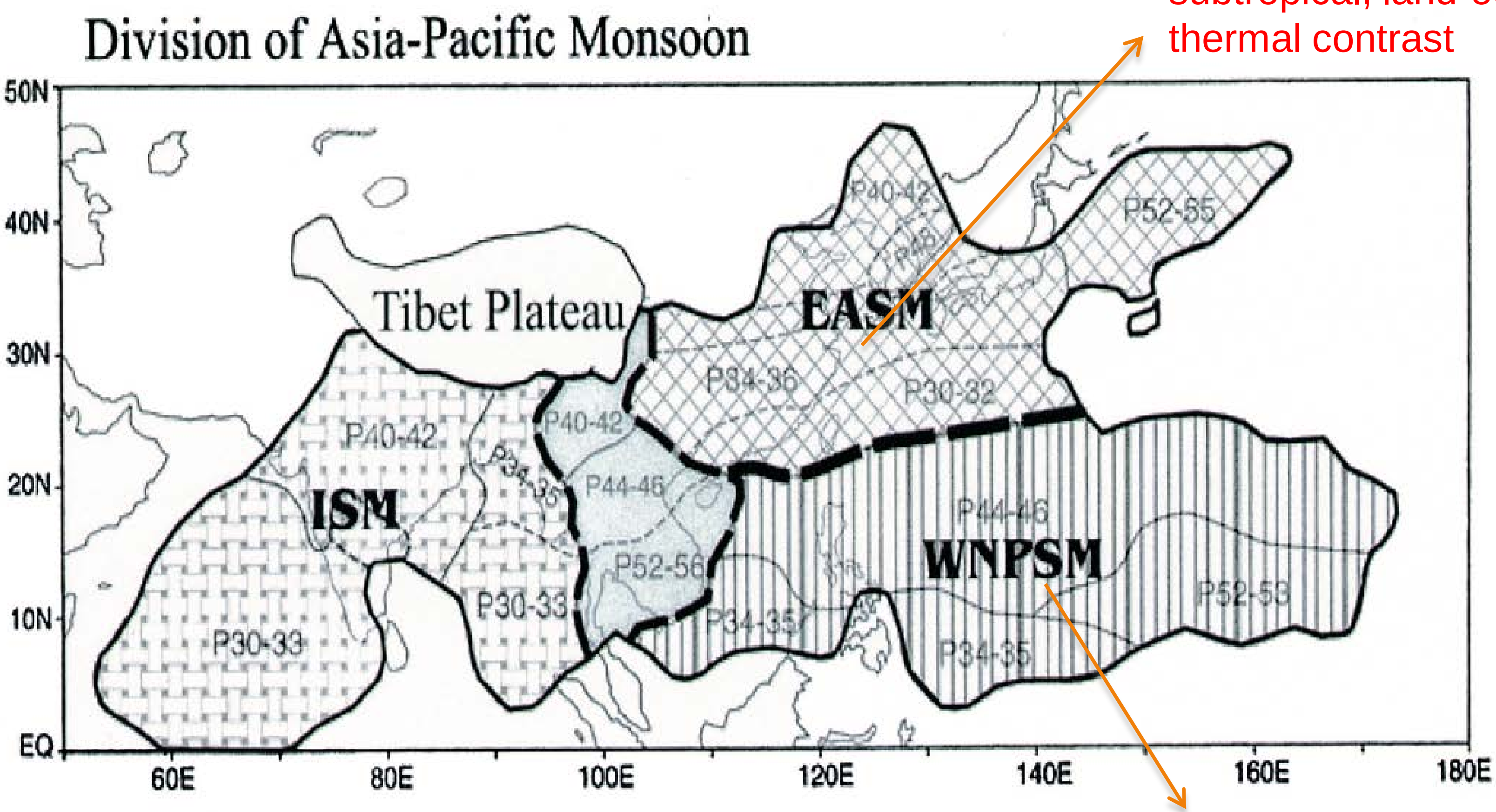
Outline

- What is East Asian-western North Pacific (EA-WNP) monsoon?
- Core system linking El Nino and EA-WNP monsoon: Western North Pacific anomalous anticyclone (WNPAC)
- Maintenance of the WNPAC during El Nino mature winter and following spring (Remote forcing from central-eastern Pacific vs. warm pool air-sea interaction)
- Maintenance of the WNPAC during El Nino decaying summer (Indian Ocean basin mode vs. local cold SSTAs)

What is EA-WNP monsoon?

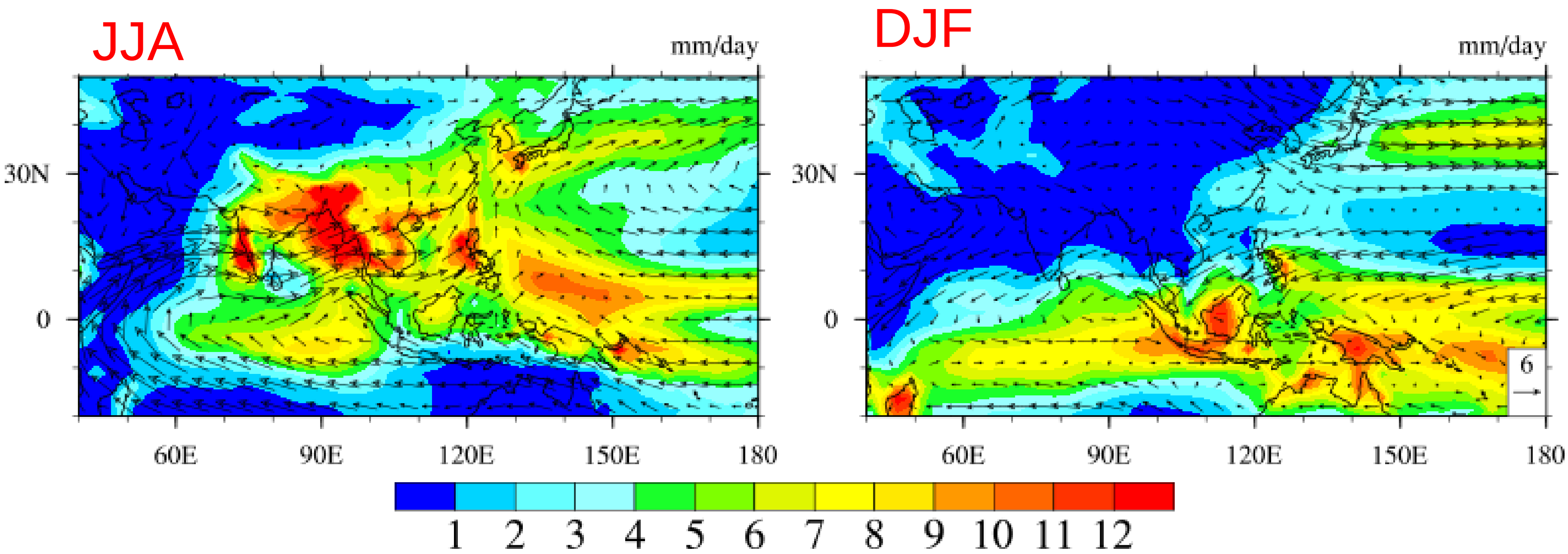
Continental monsoon, subtropical, land-ocean thermal contrast



Ocean monsoon, tropical, meridional gradient of SST

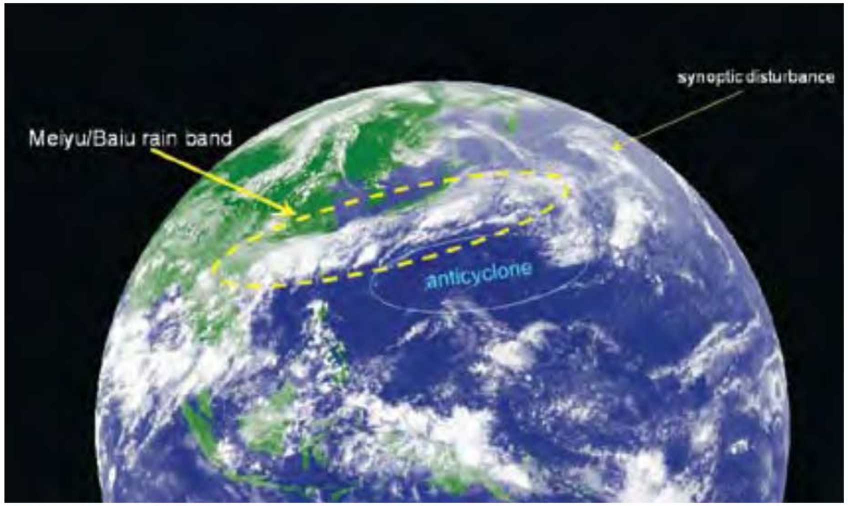
From Wang and Lin 2002

Difference between winter and summer

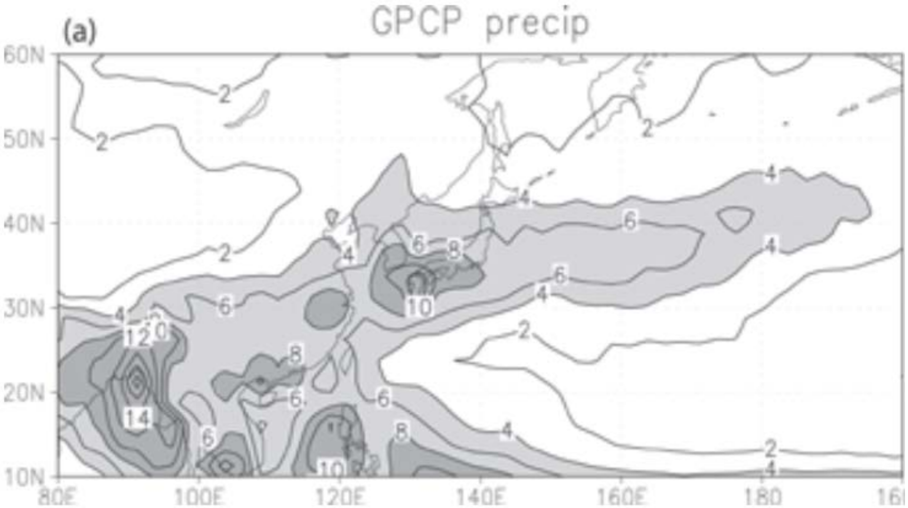


Climatological precipitation and low-level wind

Meiyu-Baiu: dominant feature of EA summer monsoon



Satellite image of Meiyu-Baiu on June 12, 2008 (by Japan Meteorological Agency).



Meiyu-Baiu rainband occurs in June and early July

From IPRC Climate

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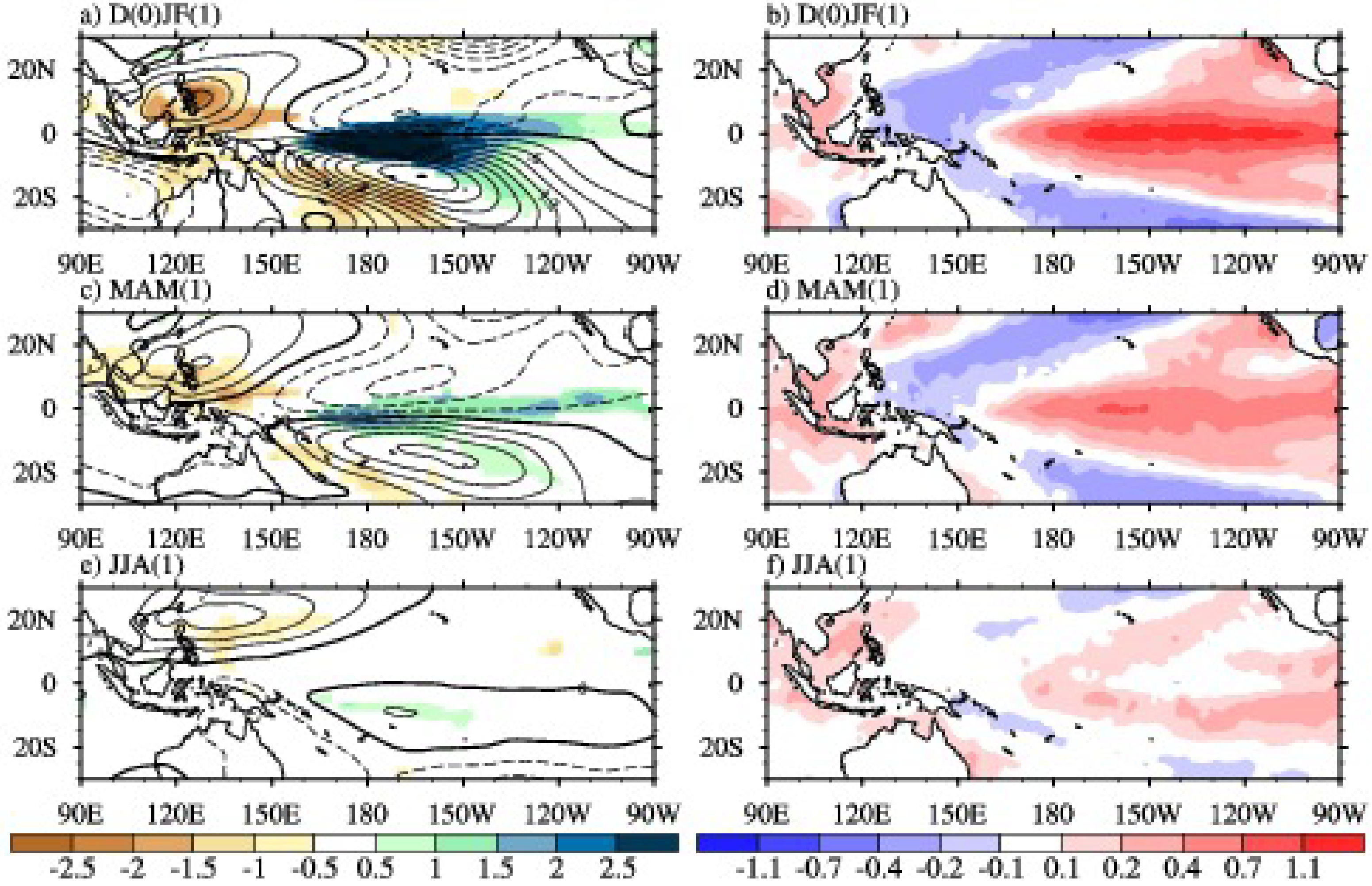
Life cycle of WNPAC

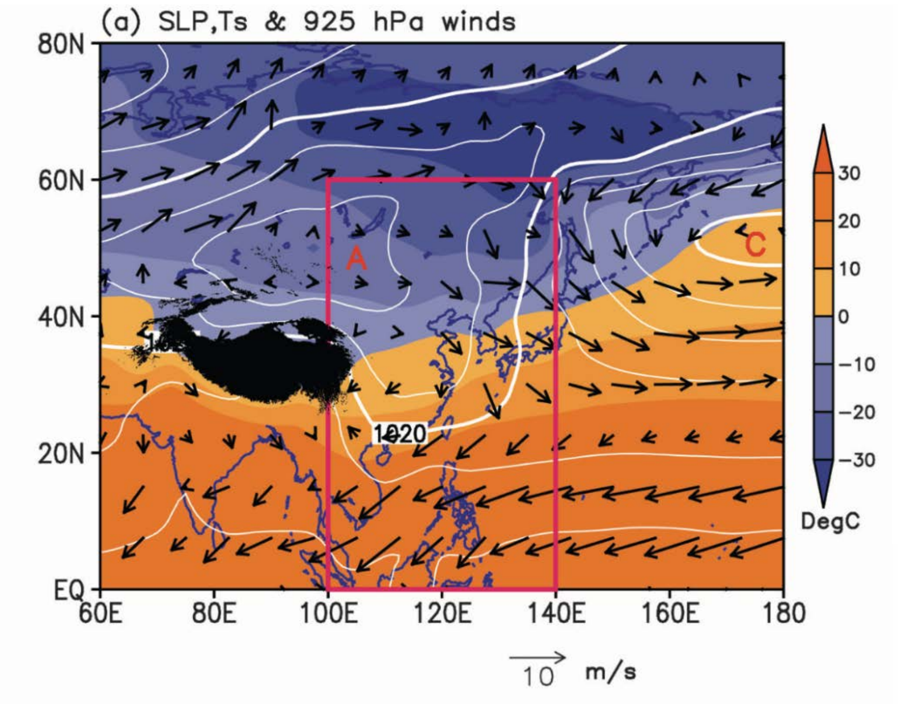
DJF

MAM

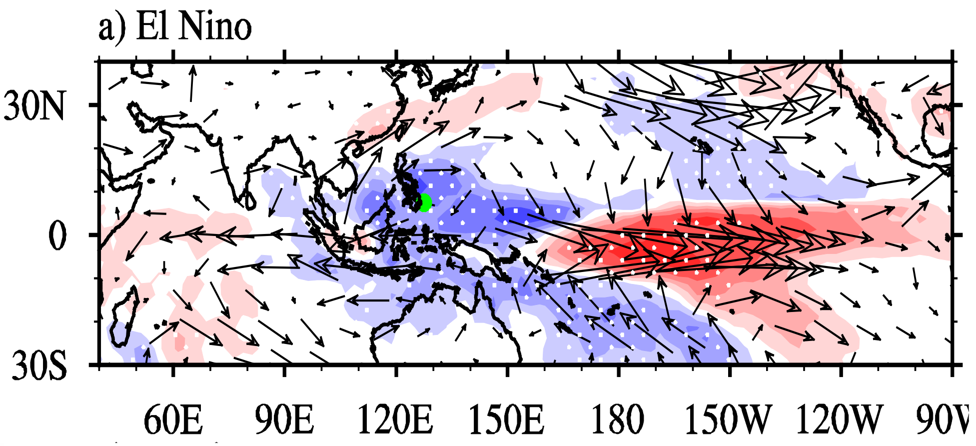
JJA



WNPAC weakens East Asian winter monsoon



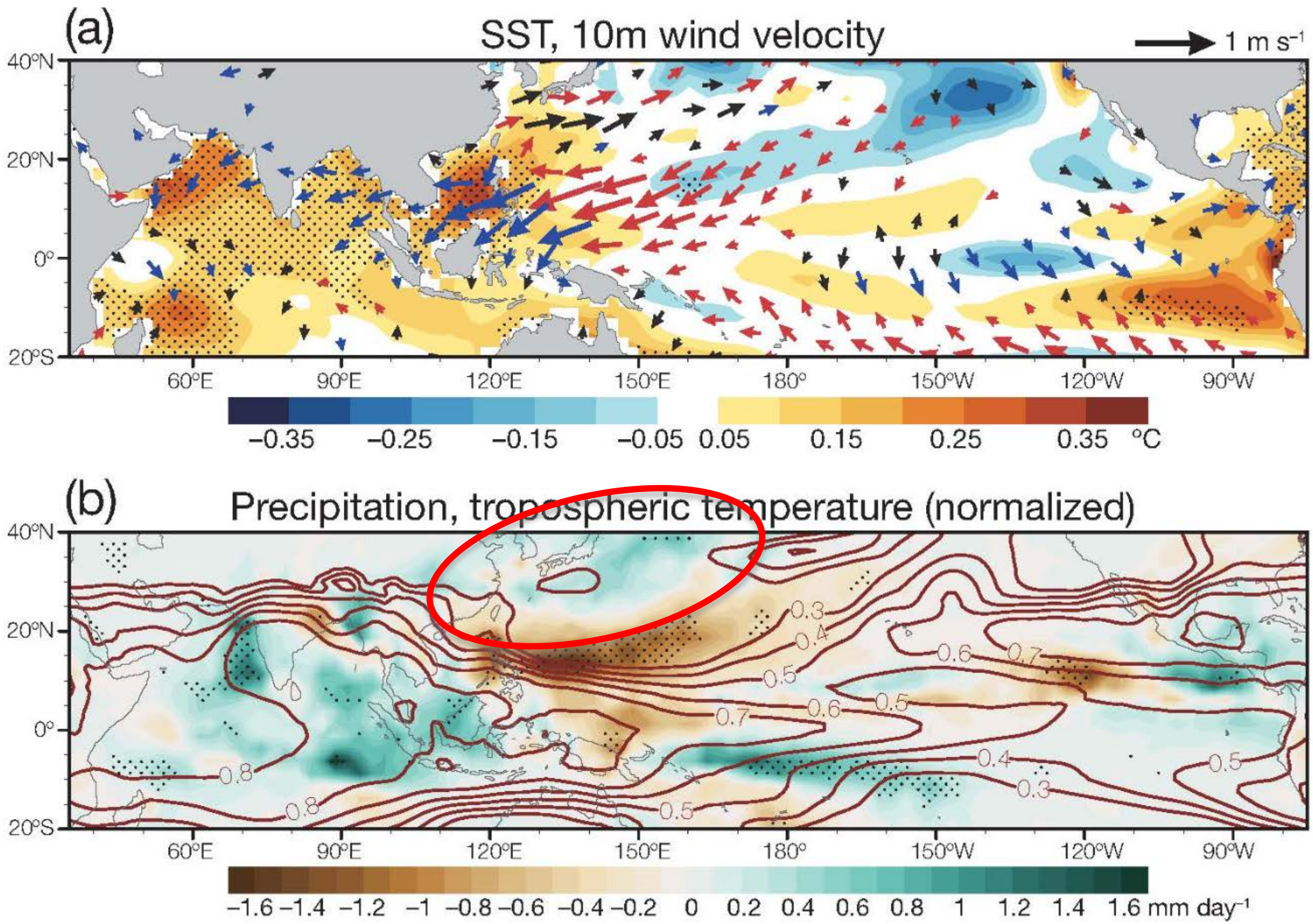
Winter climatology



El Nino winter anomalies

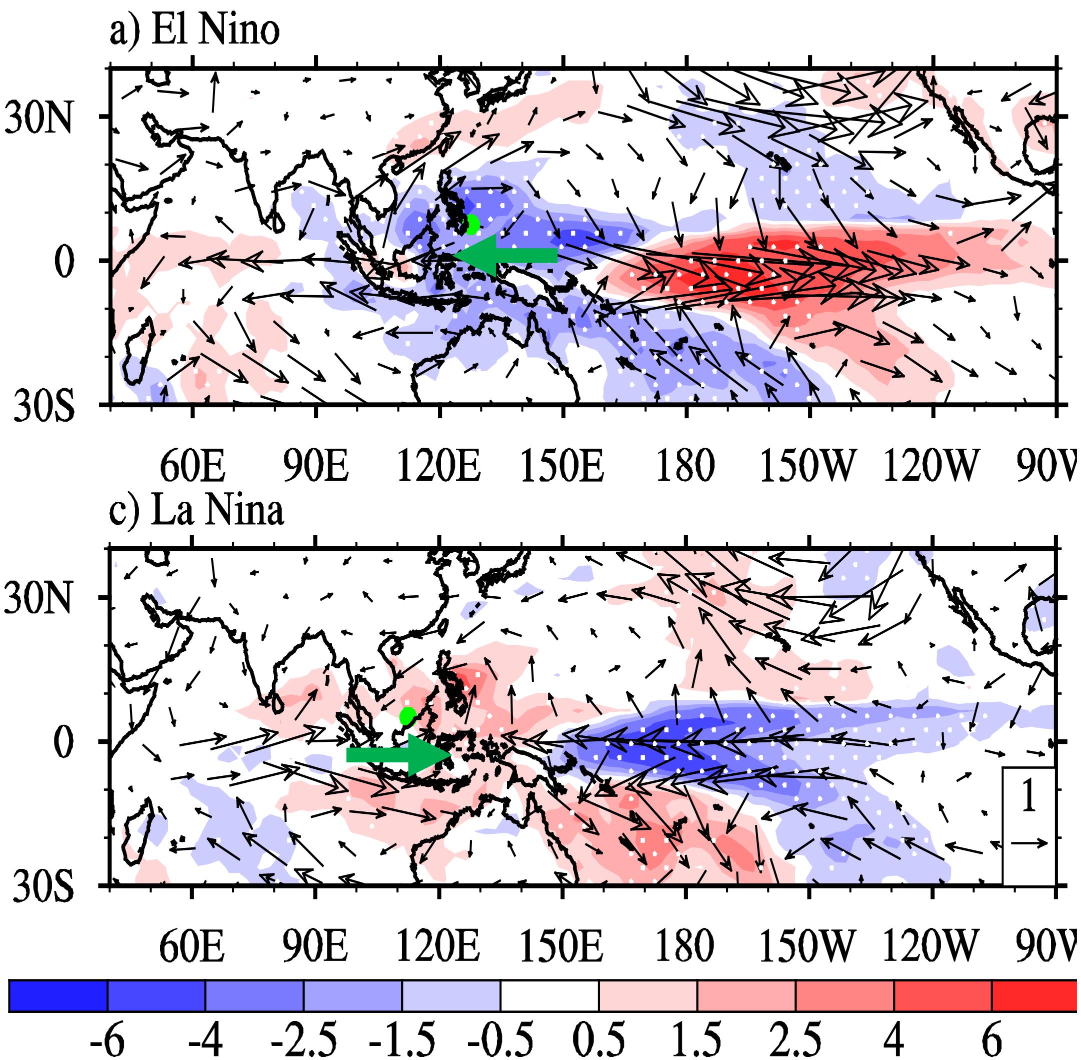
From Wang et al. 2010

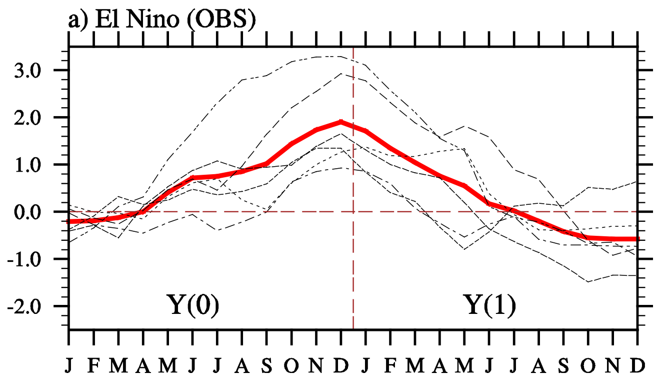
WNPAC strengthens Meiyu-Baiu precipitation

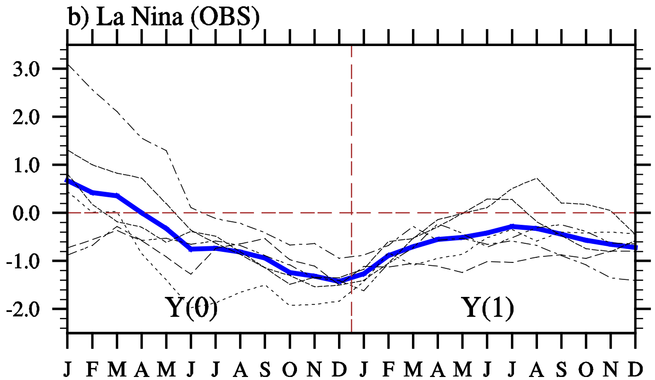


From Xie et al. 2016

WNPAC accelerates decay of El Nino







From Wu et al. 2010a

Outline

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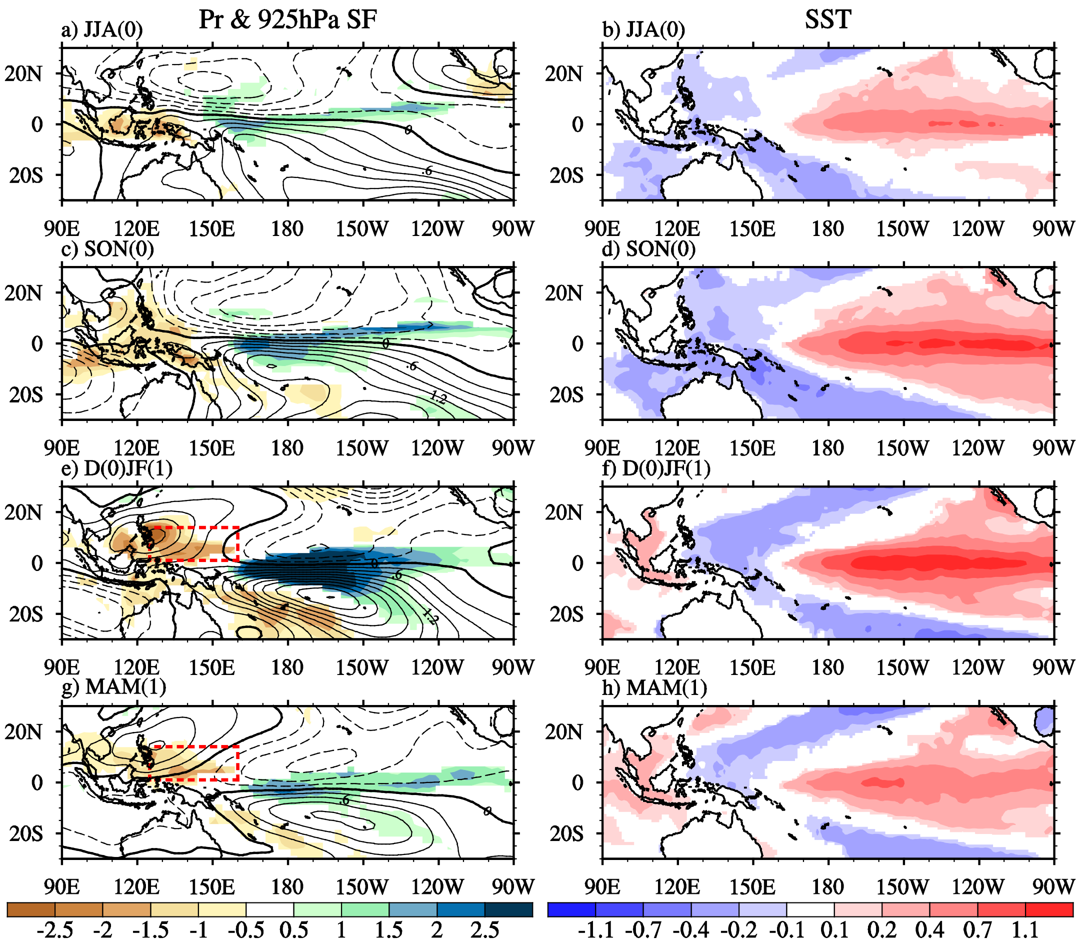
- **Core system linking El Nino and EA-WNP monsoon: Western North Pacific anomalous anticyclone (WNPAC)**
- **Maintenance of the WNPAC during El Nino mature winter and following spring (Remote forcing from central-eastern Pacific vs. warm pool air-sea interaction) (Wu et al. Part one and two)**
- **Maintenance of the WNPAC during El Nino decaying summer (Indian Ocean basin mode vs. local cold SSTAs)**

Key questions



- What is the fundamental mechanism responsible for the maintenance of the WNPAC during El Nino mature winter and following spring?
- Why the WNPAC forms in the late fall of El Nino developing phase instead of preceding summer?

Moisture equation

$$\partial_t \langle q \rangle + \langle \vec{u} \nabla_h q \rangle + \langle \omega \partial_p q \rangle = E - P$$

Moisture eq

$$\partial_t \langle q \rangle' + \langle \vec{u} \nabla_h q \rangle' + \langle \omega \partial_p q \rangle' = E' - P'$$

Monthly anomalies

$$P' \approx E' - \langle \bar{\vec{u}} \nabla_h q' \rangle - \langle \vec{u}' \nabla_h \bar{q} \rangle - \langle \bar{\omega} \partial_p q' \rangle - \langle \omega' \partial_p \bar{q} \rangle + NL$$

Moist static energy equation

$$\partial_t \left\langle (c_p T + L_v q) \right\rangle' + \left\langle \vec{u}\nabla_h (c_p T + L_v q) \right\rangle' + \left\langle \omega \partial_p h \right\rangle' = F_{net}'$$

$$F_{net} = (S_t^{\downarrow} - S_t^{\uparrow} - R_t^{\uparrow}) - (-S_s^{\uparrow} + S_s^{\downarrow} - R_s^{\uparrow} + R_s^{\downarrow} - LH - SH)$$

MSE eq

$$\left\langle \omega' \partial_p \bar{h} \right\rangle ; \quad F_{net}' - \left\langle \vec{u}\nabla_h (c_p T + L_v q)' \right\rangle - \left\langle \vec{u}' \nabla_h \overline{(c_p T + L_v q)} \right\rangle - \left\langle \bar{\omega} \partial_p h' \right\rangle + NL$$

Monthly anomalies

Methods

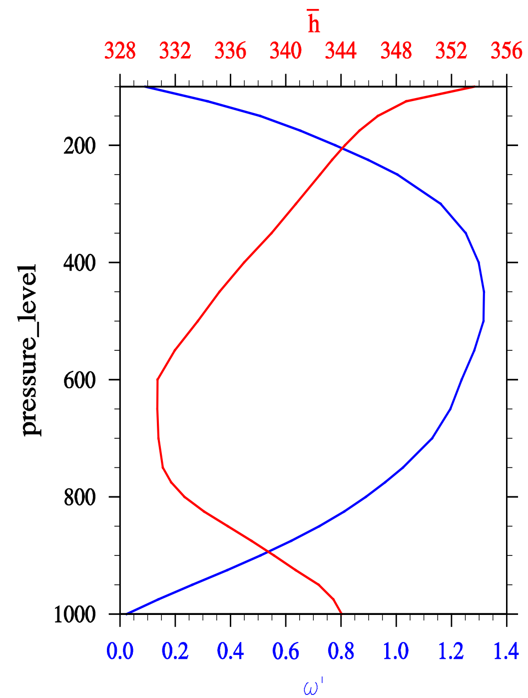
Moisture equation

$$P' \; ; \; E' - \left\langle \vec{u} \nabla_h q' \right\rangle - \left\langle \vec{u}' \nabla_h \overline{q} \right\rangle - \left\langle \overline{\omega} \partial_p q' \right\rangle - \left\langle \omega' \partial_p \overline{q} \right\rangle + NL$$

Moist static energy (MSE) equation

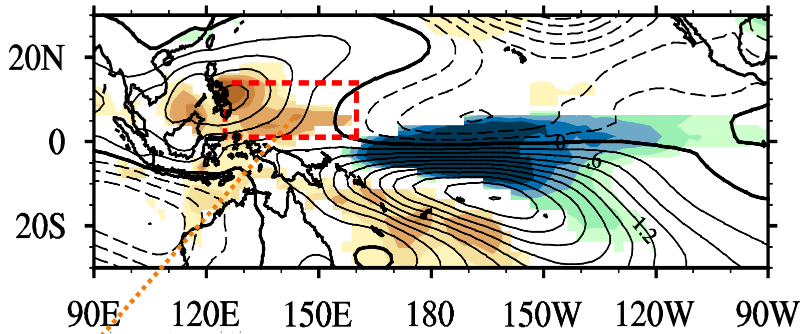
$$\left\langle \omega' \partial_p \overline{h} \right\rangle \; ; \; F_{net}' - \left\langle \vec{u} \nabla_h (c_p T + L_v q)' \right\rangle - \left\langle \vec{u}' \nabla_h \overline{(c_p T + L_v q)} \right\rangle - \left\langle \overline{\omega} \partial_p h' \right\rangle + NL$$

- In the tropics with deep convection, the vertical motion is constrained by the MSE budget balance
- If the physical processes in the right hand size of MSE equation tend to reduce the MSE in the column, descending anomalies should be generated



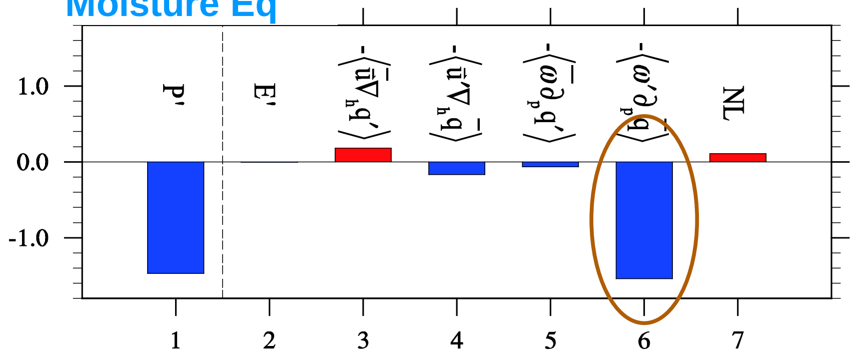
Moisture and MSE budget analysis

D(0)JF(1)



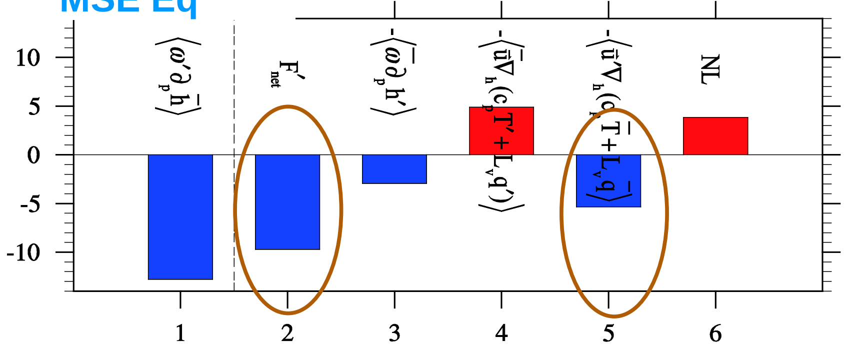
Shading: Precipitation
Contour: 925hPa stream function

Moisture Eq



$$P' \; ; \; -\langle \omega' \partial_p \bar{q} \rangle$$

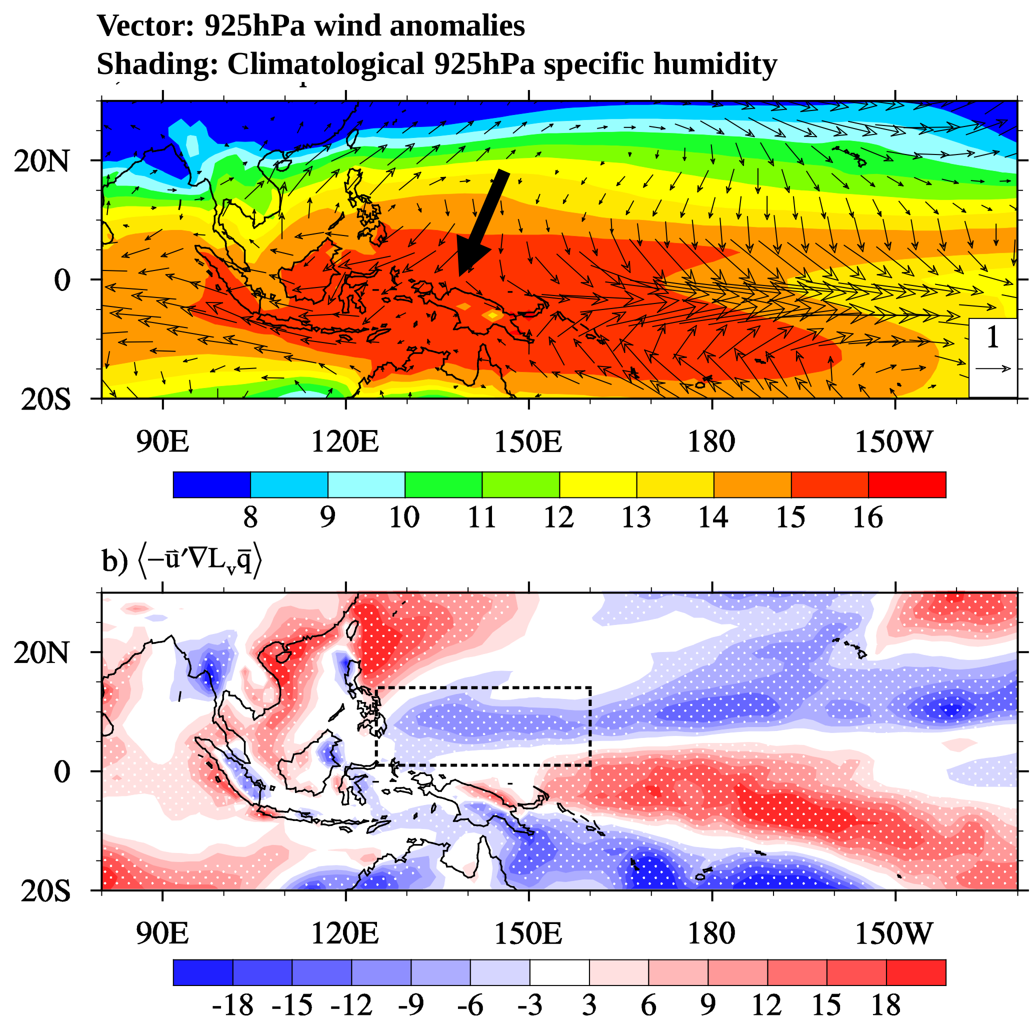
MSE Eq



$$\langle \omega' \partial_p \bar{h} \rangle \sim F_{net}' - \langle v' \nabla_h \overline{(c_p T + L_v q)} \rangle$$

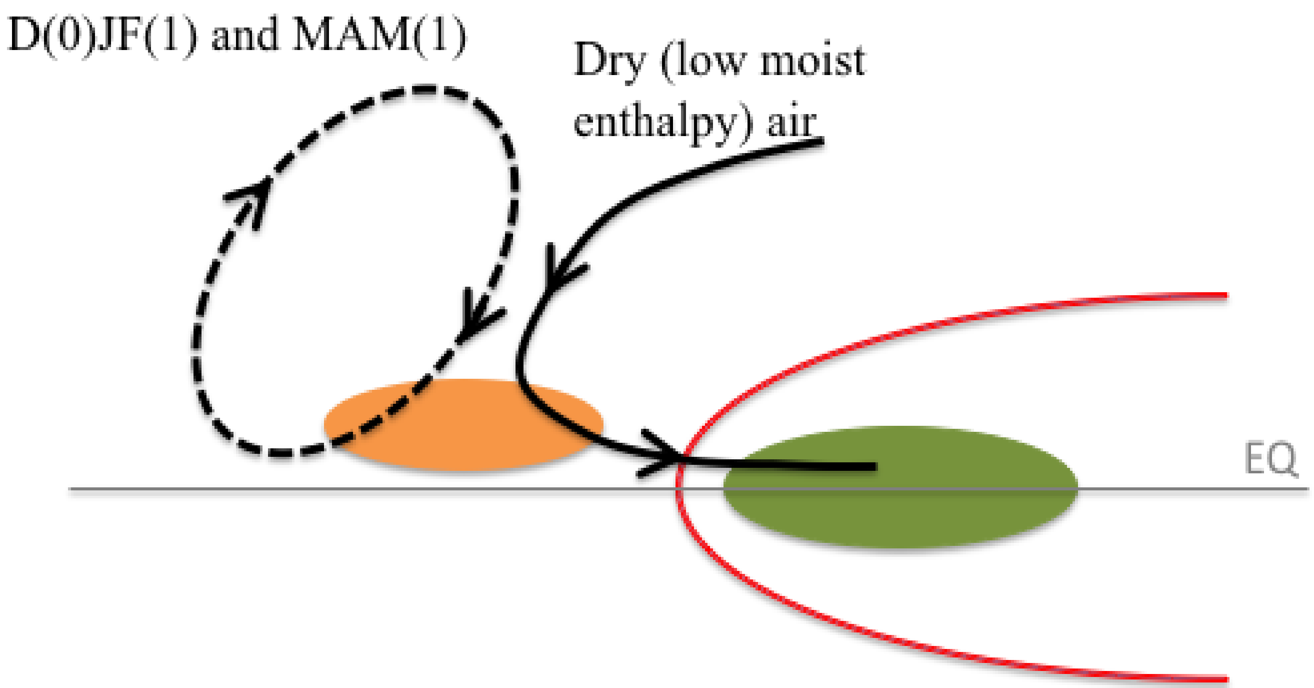
$$R'_{cloud} \qquad \langle -v' \cdot \nabla(\overline{L_v q}) \rangle$$

Horizontal advection of climatological moist enthalpy by anomalous wind

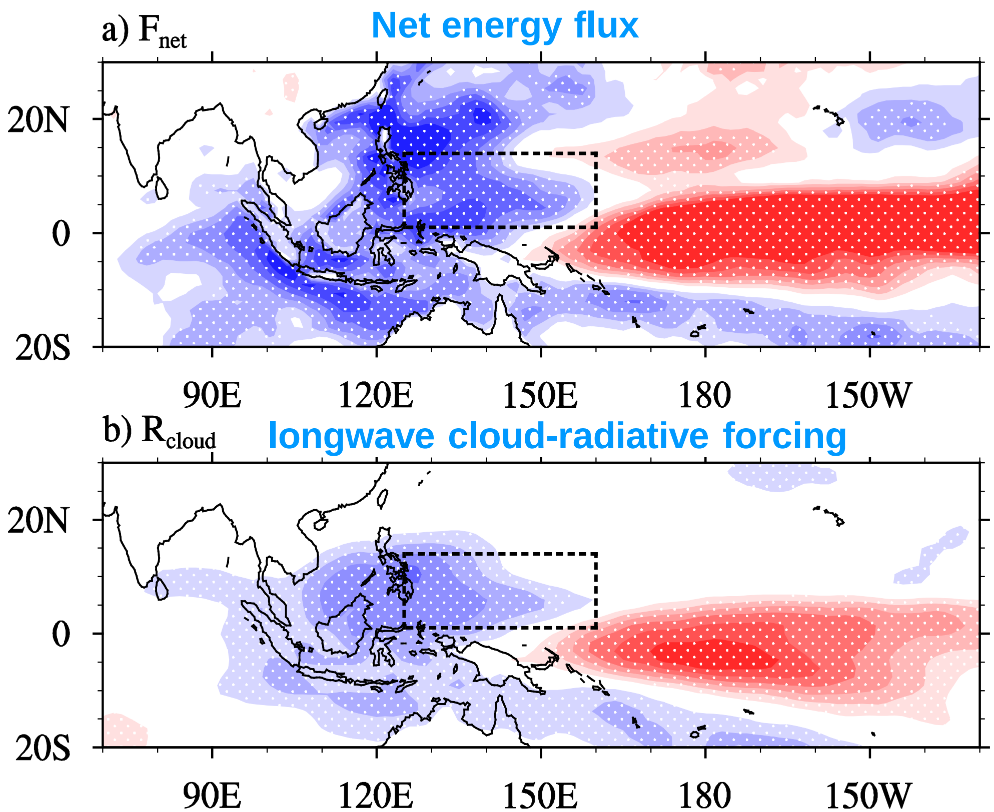


- Climatological specific humidity has negative meridional gradient
- The positive precipitation anomalies over the equatorial CEP excite twin cyclone anomalies
- The anomalous northerly component advects dry air into the tropical WNP

Schematic of the anomalous moist enthalpy advection mechanism



Internal positive “convection–cloud-radiative forcing” feedback

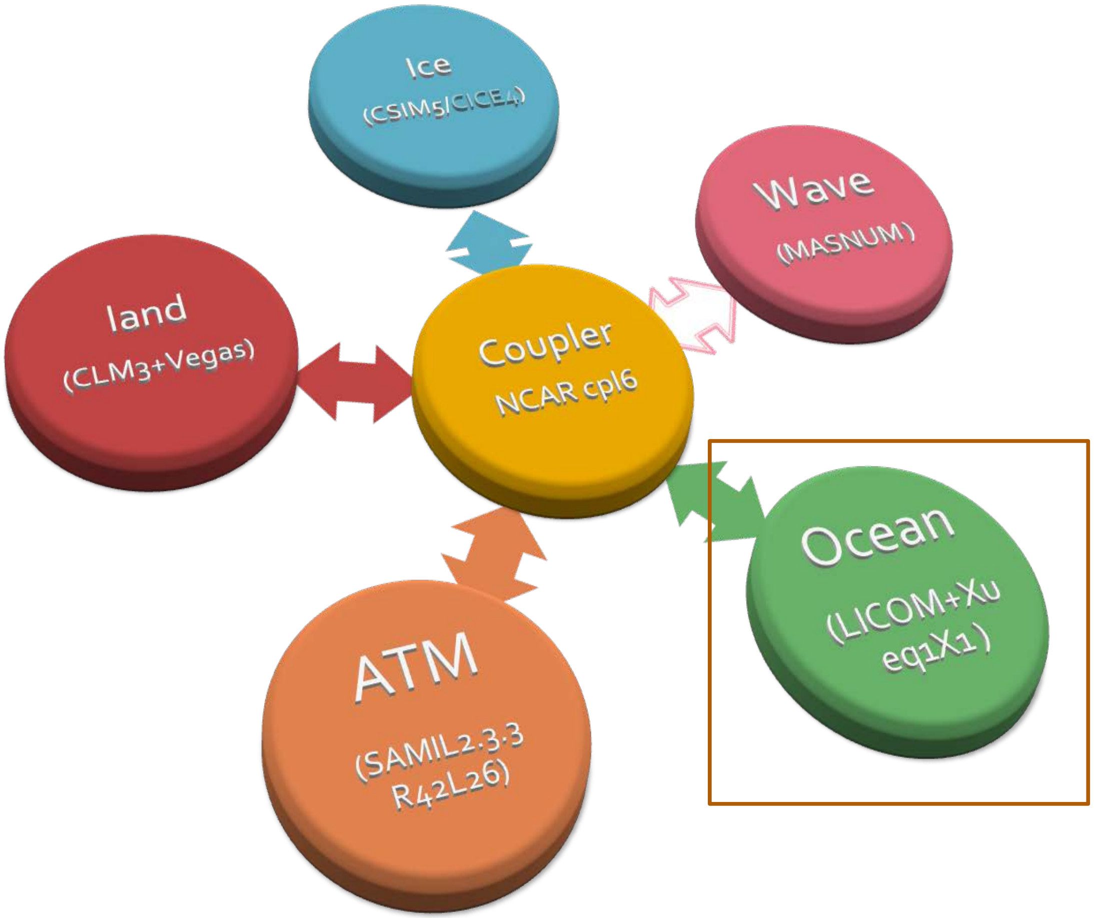


$$F_{net}' = R_{cloud}' + R_{clear}' + S_{net}' + LH' + SH'$$

More than 60% contribution

- Longwave cloud-radiative forcing anomalies are generated by an internal positive feedback in the tropical atmosphere
- Suppressed deep convection → decrease of deep convective cloud → Weakening of the warming effect of the longwave cloud-radiative forcing → Suppressed deep convection

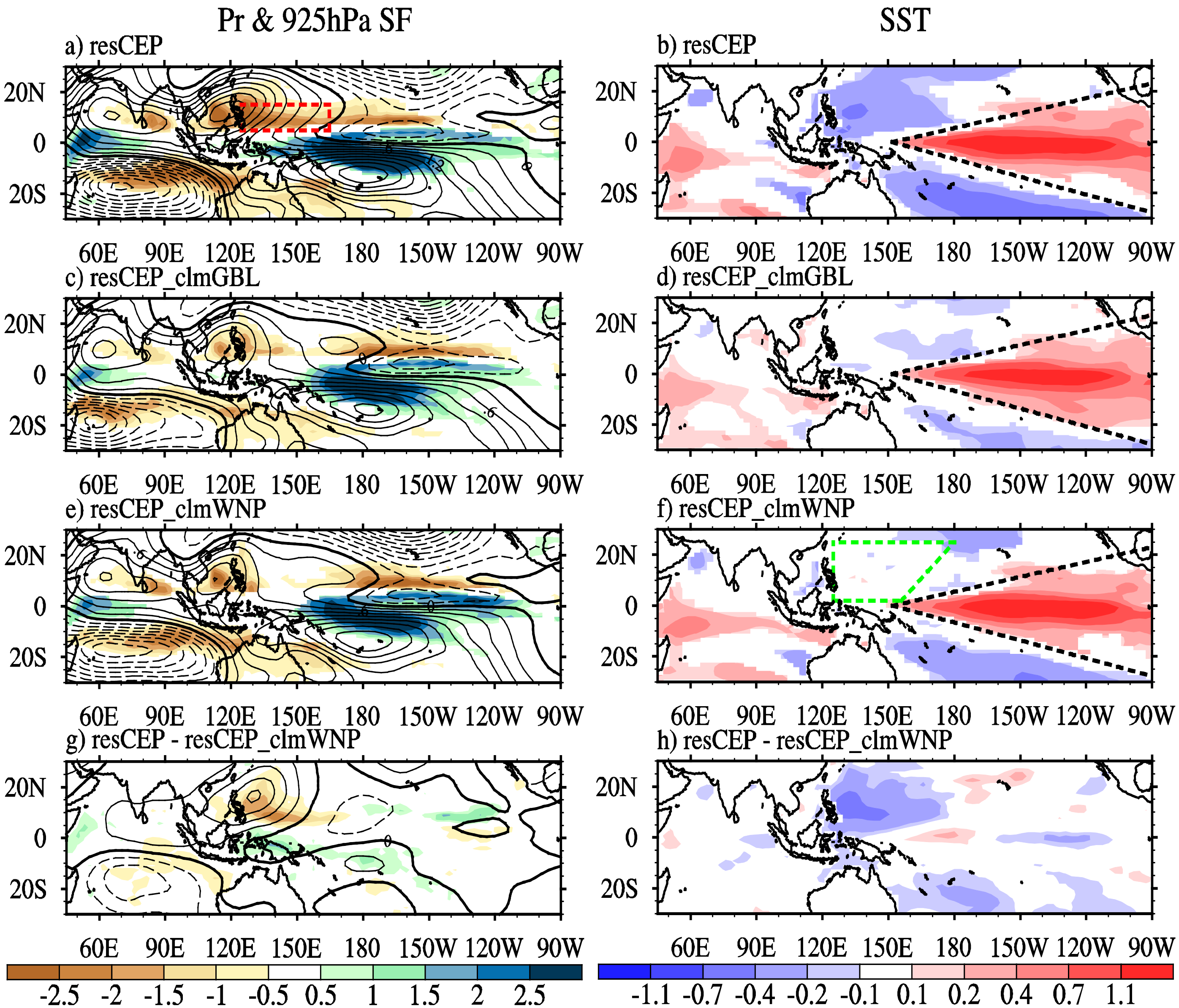
Pacemaker experiment



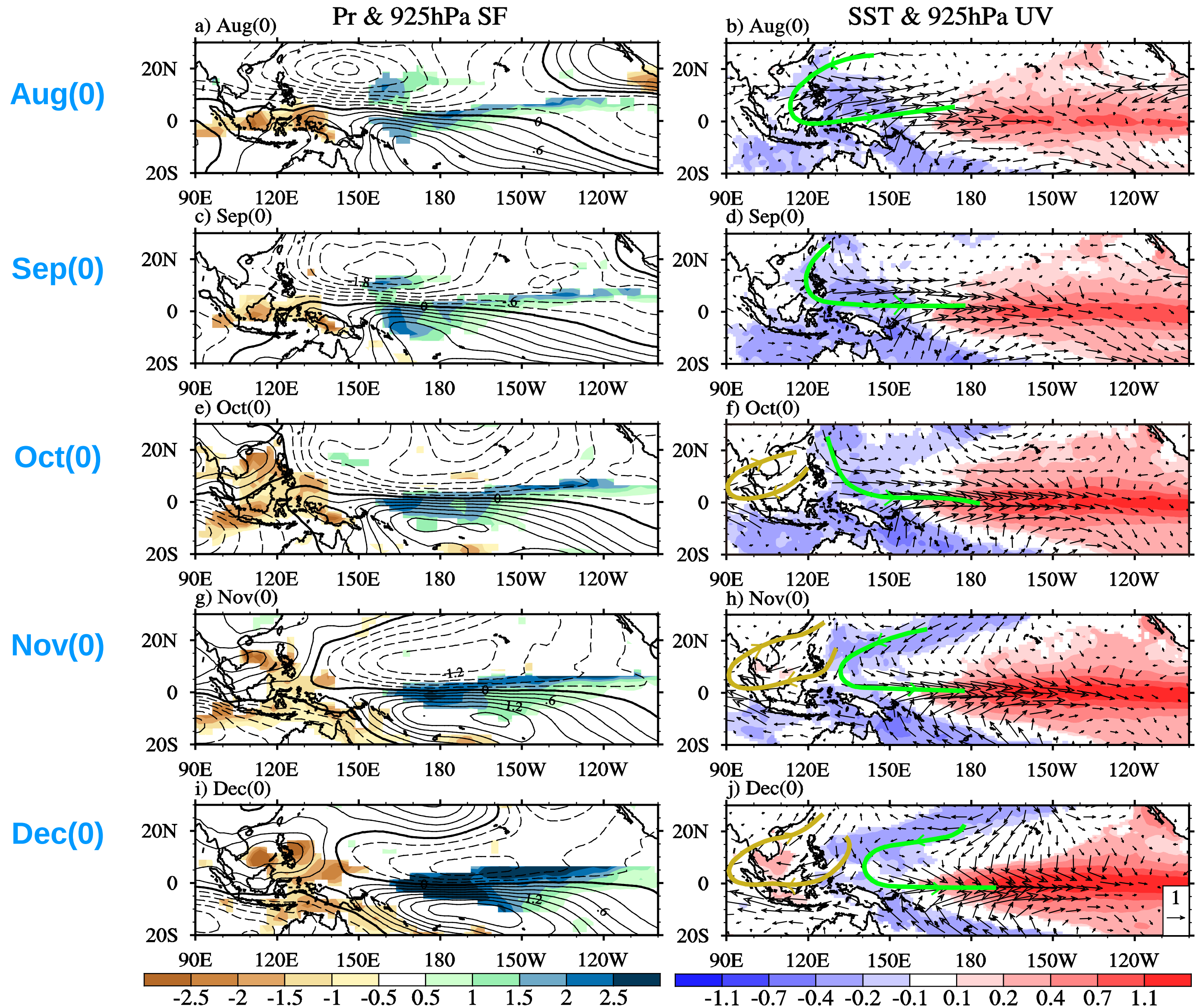
Restore ocean Temp in equatorial CEP to OBS

FGOALS-s2 is a Coupled GCM

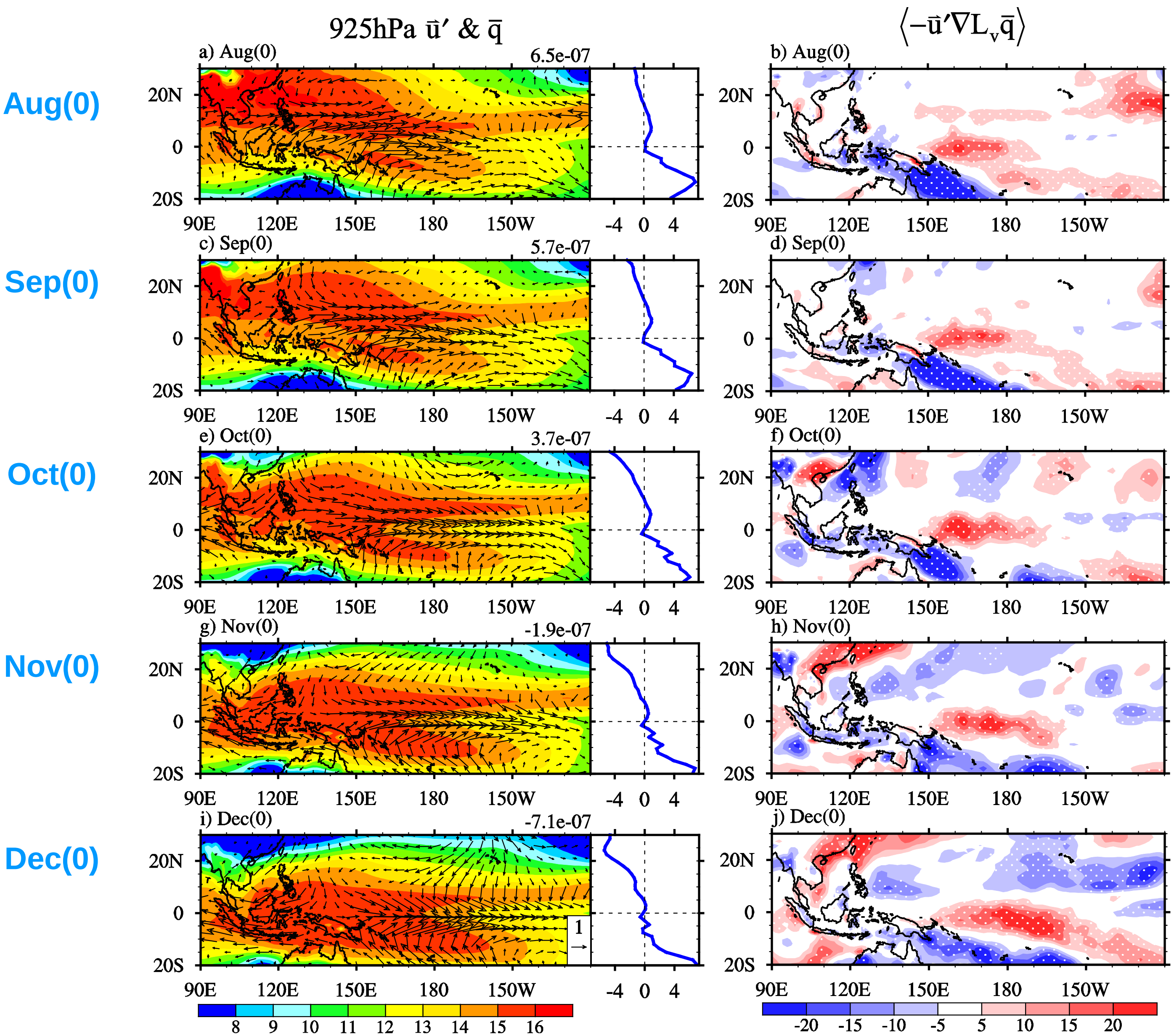
Idealized numerical experiments by an CGCM FGOALS-s2



Formation process of the WNPAC



Temporal evolution of anomalous advection of moist enthalpy



Temporal evolution of precipitation

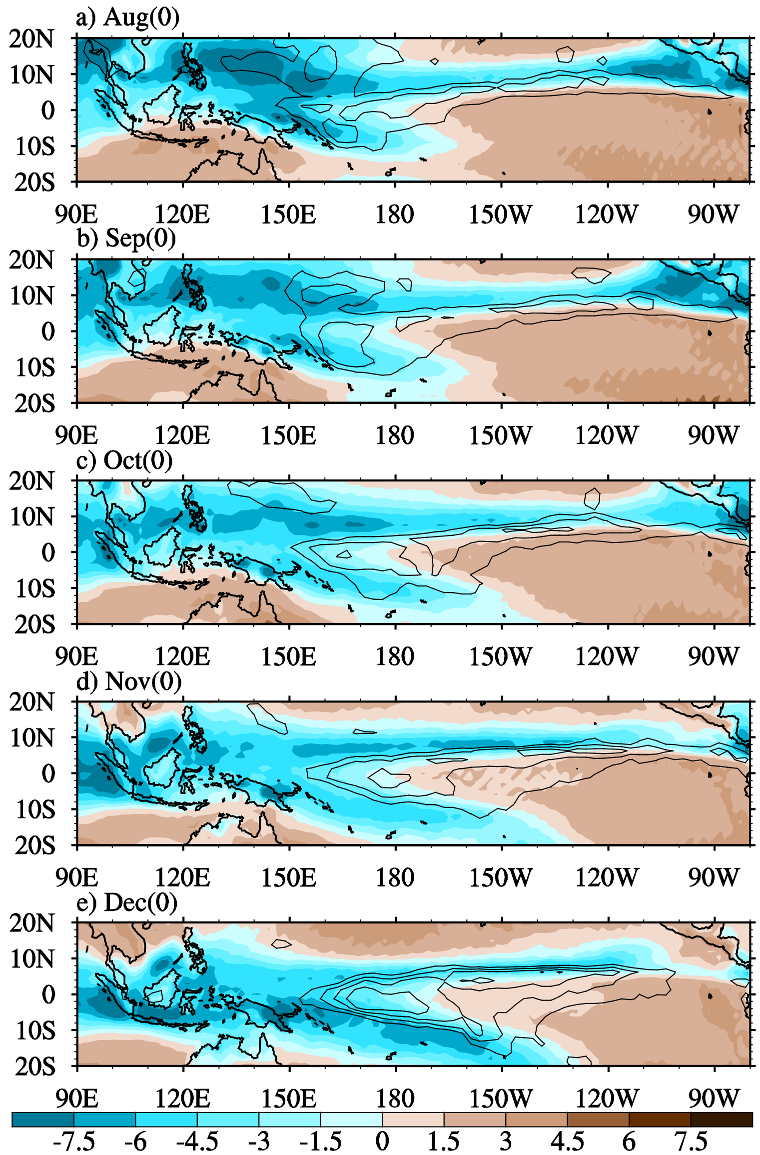
Aug(0)

Sep(0)

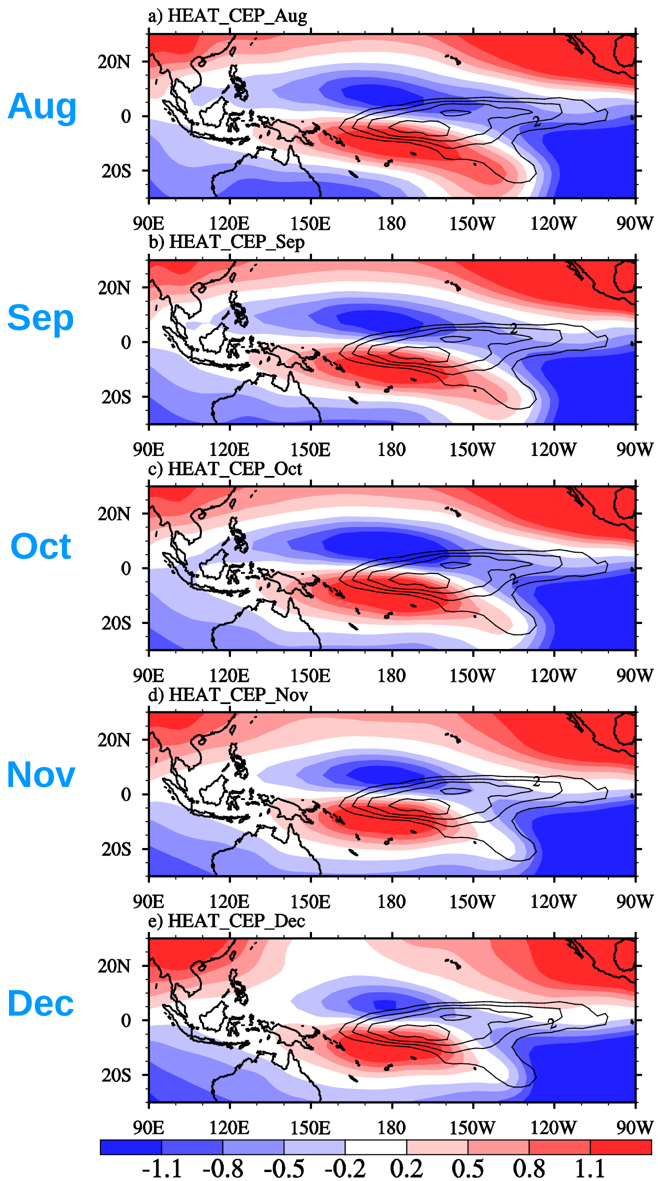
Oct(0)

Nov(0)

Dec(0)

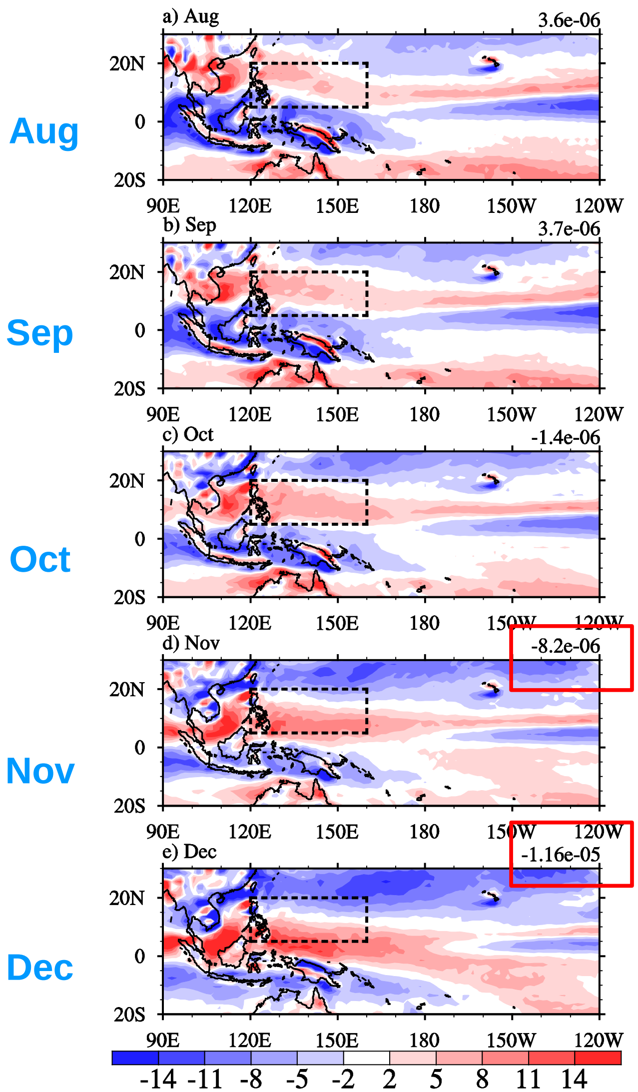


Idealized numerical experiments by an dry AGCM

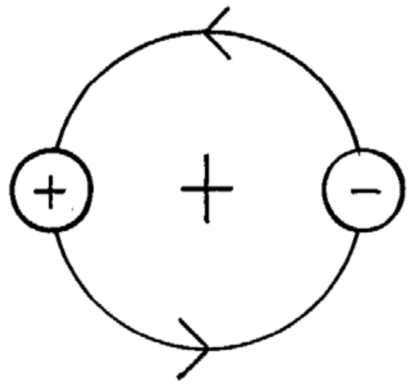


- Constructed the heating field using the pattern of the positive precipitation anomalies over the equatorial CEP during the El Niño mature winter.
- The heating field was used to drive the model, with the background mean states specified as the climatology of August, September, October, November and December derived from the reanalysis data

Sign change of the meridional gradient of background relative vorticity



climatological relative vorticity



From Hoskins and Ambrizzi 1993

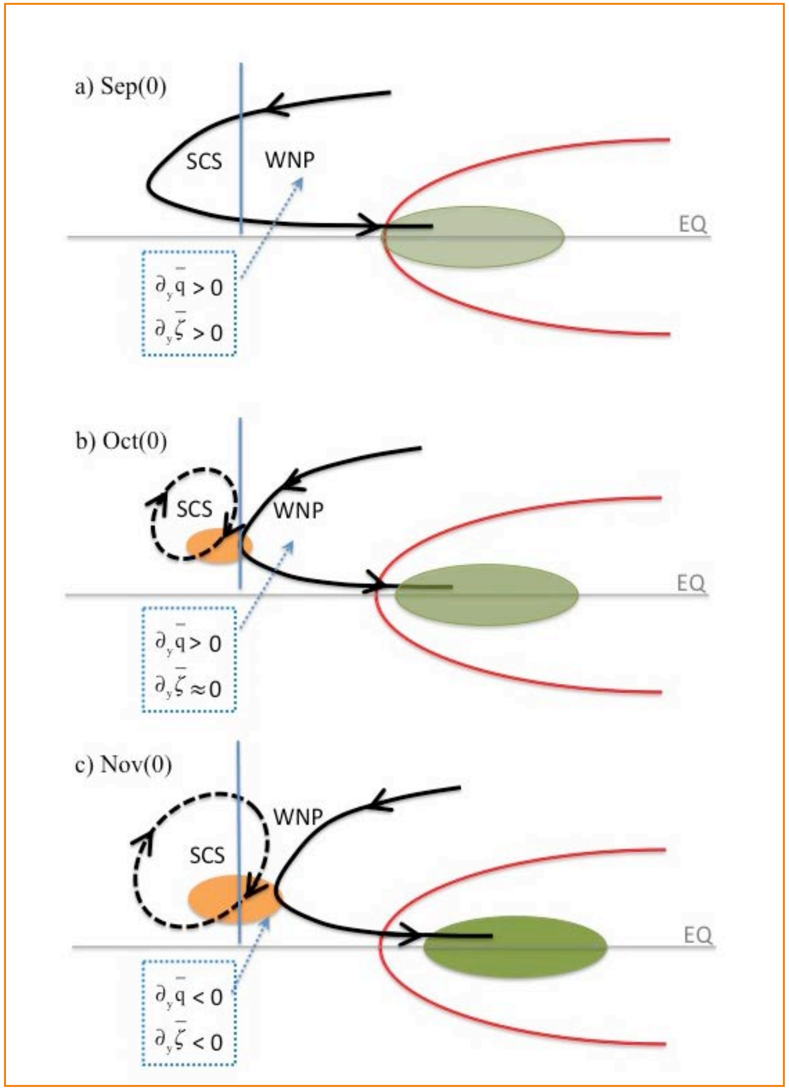
- The meridional gradient of the voriticity over the WNP transforms from positive to negative.
- The sign change in late fall increasingly offsets the beta effect and thus reduces the **westward stretch of the Rossby-wave gyre anomalies**.
- The northern branch of the twin cyclonic anomalies induced by the El Niño heating withdraws eastward, leaving space for the formation of the WNPAC.

Schematic of the formation of the WNPAC

Sep(0)

Oct(0)

Nov(0)



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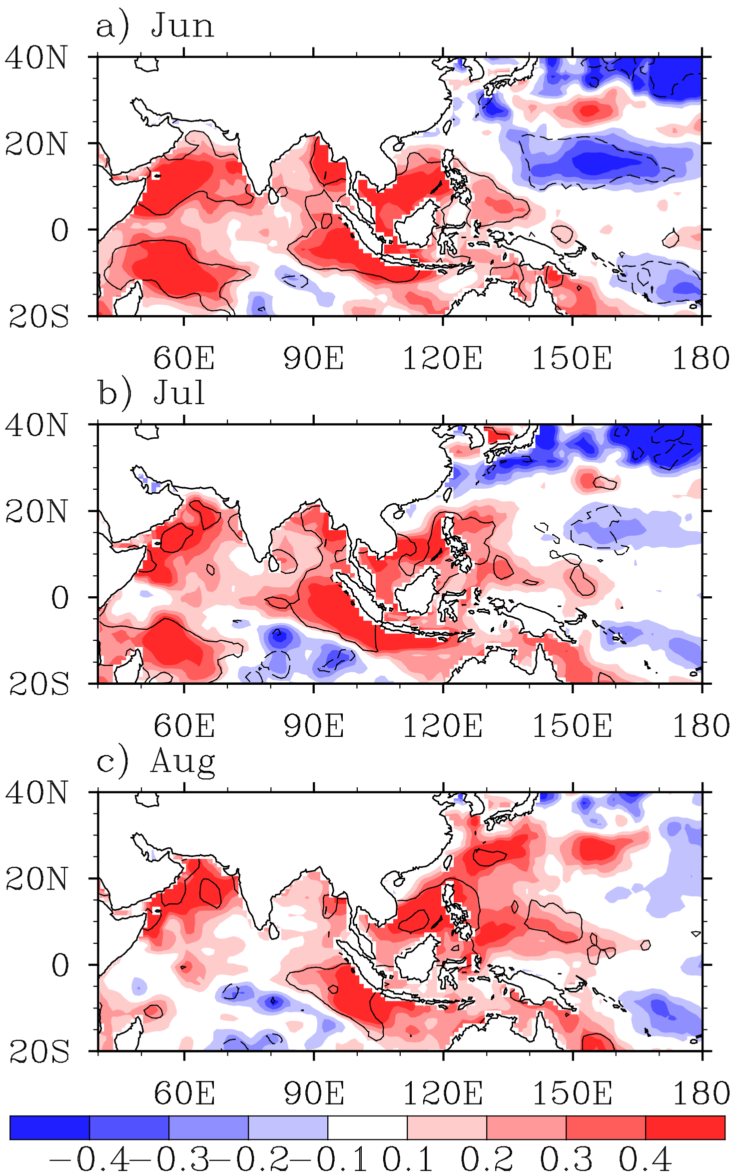
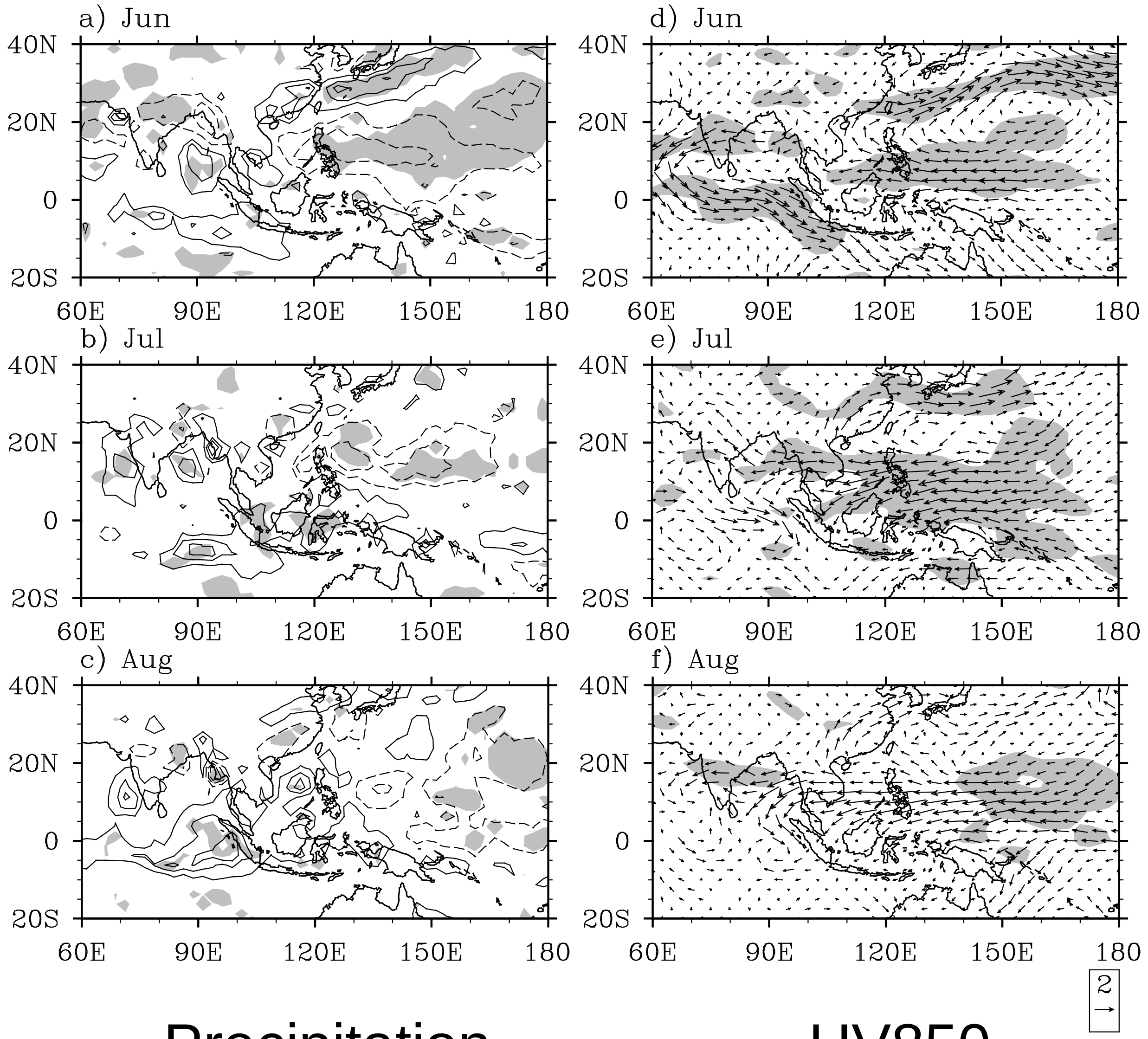
SSTAs during El Nino decaying summer



- Cold SSTA in the WNP gradually decay and withdraw eastward from June to August.
- Indian Ocean basin mode (IOBM) maintains throughout the summer.

From Wu et al. 2010b

WNPAC maintains throughout the summer

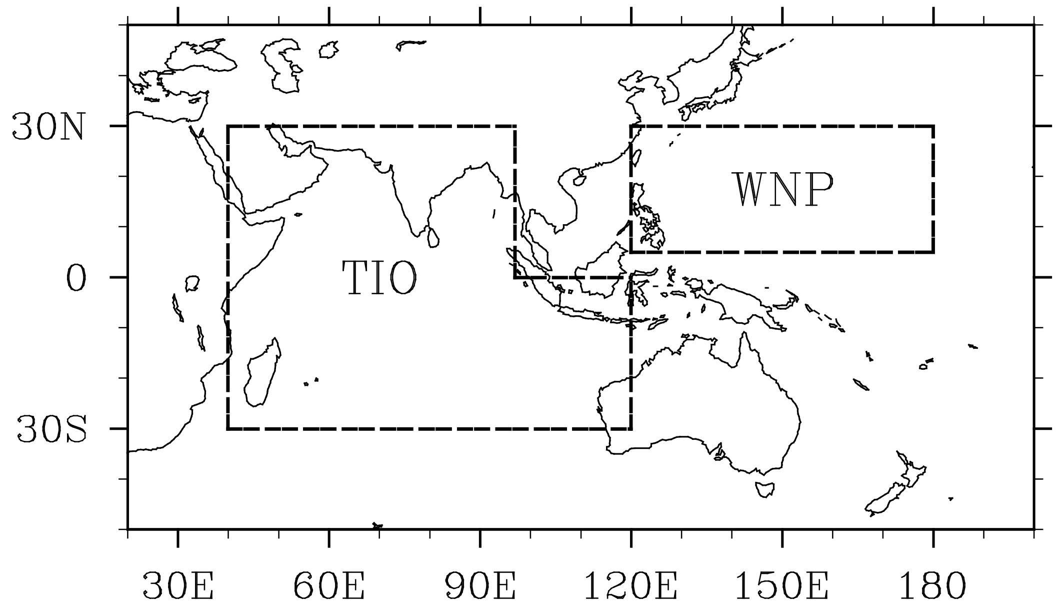


Precipitation

UV850

From Wu et al. 2010b

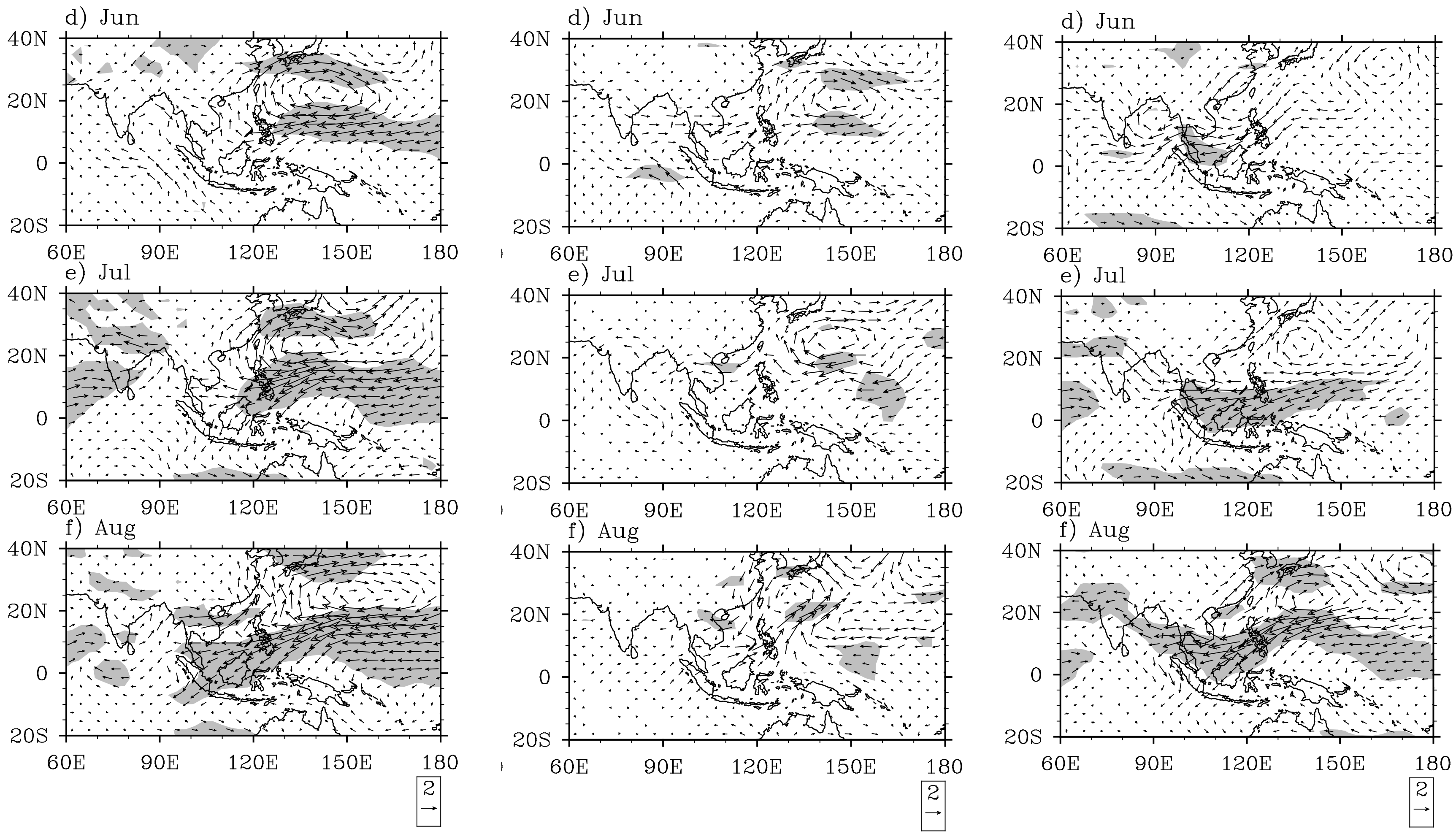
Idealized numerical experiments by AGCM



Experiment	SST forcing	Integration
Control run (CTRL)	Global climatological SST	20 years
Global forcing (GB)	Add SSTA to climatological SST in global ocean	20 realizations
Indian Ocean forcing (TIO)	Add SSTA to climatological SST in the tropical Indian Ocean only	20 realizations
Western North Pacific forcing (WNP)	Add SSTA to climatological SST in the western North Pacific only	20 realizations

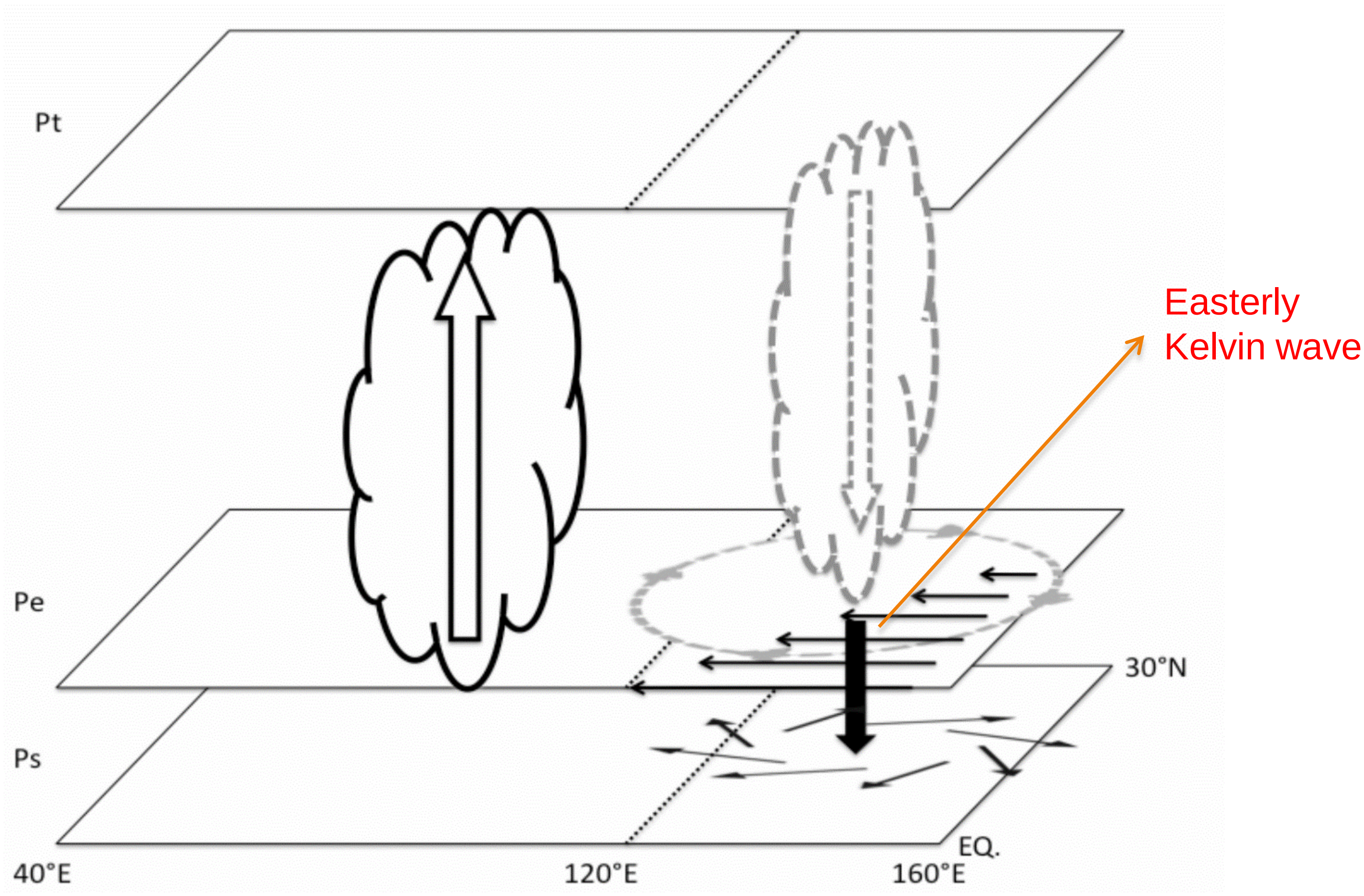
Relative contributions of TIO and WNP

GB | WNP | TIO



From Wu et al. 2010b

How IOBM drives WNPAC?



From Wu et al. 2009

Summary

- WNPAC plays a central role in linking El Nino and EA-WNP monsoon
- WNPAC maintains from El Nino developing winter to decaying summer
- WNPAC is driven by El Nino remote forcing through moist enthalpy advection mechanism during El Nino developing winter and following spring
- WNPAC is driven by Indian Ocean basin wide warming and local cold SSTAs during El Nino decaying summer

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Thank You !