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

JJA

DJF

Climatological precipitation and low-level wind
Meiyu-Baiu: dominant feature of EA summer monsoon

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
• 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) (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

\[ \partial_t \langle q \rangle + \langle u \nabla_h q \rangle + \langle \omega \partial_p q \rangle = E - P \]

Monthly anomalies

\[ \partial_t \langle q \rangle' + \langle u \nabla_h q \rangle' + \langle \omega \partial_p q \rangle' = E' - P' \]

\[ P' \approx E' - \langle u \nabla_h q' \rangle - \langle u' \nabla_h q \rangle - \langle \omega \partial_p q' \rangle - \langle \omega' \partial_p q \rangle + NL \]
Moist static energy equation

\[ \frac{\partial_t}{\partial t} \left\langle (c_p T + L_v q) \right\rangle' + \left\langle \nabla_h (c_p T + L_v q) \right\rangle' + \left\langle \omega \partial_p h \right\rangle' = F_{net}' \]

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

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

Monthly anomalies
Methods

Moisture equation

\[ P' - E' - \left\langle \nabla u \nabla_h q' \right\rangle - \left\langle \nabla u \nabla_h q \right\rangle - \left\langle \omega \partial_p q' \right\rangle - \left\langle \omega' \partial_p q \right\rangle + NL \]

Moist static energy (MSE) equation

\[ \left\langle \omega' \partial_p \bar{h} \right\rangle; \ F_{net}' - \left\langle \nabla u \nabla_h (c_p T + L_v q)' \right\rangle - \left\langle \nabla u \nabla_h (c_p T + L_v q) \right\rangle - \left\langle \omega \partial_p h' \right\rangle + NL \]

- 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

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

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

\[ R'_{\text{cloud}} \sim \langle -v' \cdot \nabla (L_v q) \rangle \]
• 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

D(0)JF(1) and MAM(1)

Dry (low moist enthalpy) air

EQ
Internal positive “convection–cloud-radiative forcing” feedback

- 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

Net energy flux:

\[
F_{\text{net}}' = R_{\text{cloud}}' + R_{\text{clear}}' + S_{\text{net}}' + LH' + SH'
\]

More than 60% contribution
FGOALS-s2 is a Coupled GCM

Pacemaker experiment

Restore ocean Temp in equatorial CEP to OBS
Idealized numerical experiments by an CGCM FGOALS-s2
Formation process of the WNPAC
Temporal evolution of anomalous advection of moist enthalpy

Aug(0)

Sep(0)

Oct(0)

Nov(0)

Dec(0)
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

- The meridional gradient of the vorticity 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.

From Hoskins and Ambrizzi 1993
Schematic of the formation of the WNPAC

- **Sep(0)**
  - SCS
  - WNP
  - $\frac{\partial_q}{\partial z} > 0$
  - $\frac{\partial_q}{\partial \zeta} > 0$

- **Oct(0)**
  - SCS
  - WNP
  - $\frac{\partial_q}{\partial z} > 0$
  - $\frac{\partial_q}{\partial \zeta} = 0$

- **Nov(0)**
  - SCS
  - WNP
  - $\frac{\partial_q}{\partial z} < 0$
  - $\frac{\partial_q}{\partial \zeta} < 0$
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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

From Wu et al. 2010b
### Idealized numerical experiments by AGCM

<table>
<thead>
<tr>
<th>Experiment</th>
<th>SST forcing</th>
<th>Integration</th>
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</thead>
<tbody>
<tr>
<td>Control run (CTRL)</td>
<td>Global climatological SST</td>
<td>20 years</td>
</tr>
<tr>
<td>Global forcing (GB)</td>
<td>Add SSTA to climatological SST in global ocean</td>
<td>20 realizations</td>
</tr>
<tr>
<td>Indian Ocean forcing (TIO)</td>
<td>Add SSTA to climatological SST in the tropical Indian Ocean only</td>
<td>20 realizations</td>
</tr>
<tr>
<td>Western North Pacific forcing (WNP)</td>
<td>Add SSTA to climatological SST in the western North Pacific only</td>
<td>20 realizations</td>
</tr>
</tbody>
</table>
Relative contributions of TIO and WNP

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
Wang, B., et al., 2010: Another Look at Interannual-to-Interdecadal Variations of the East Asian Winter Monsoon: The Northern and Southern Temperature Modes. J. Climate,


Li and Wang, 2005: A Review on the Western North Pacific Monsoon: Synoptic-to-Interannual Variabilities

Thank You!