Evaluation of wintertime Pacific North America Teleconnection in E3SM

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Introduction

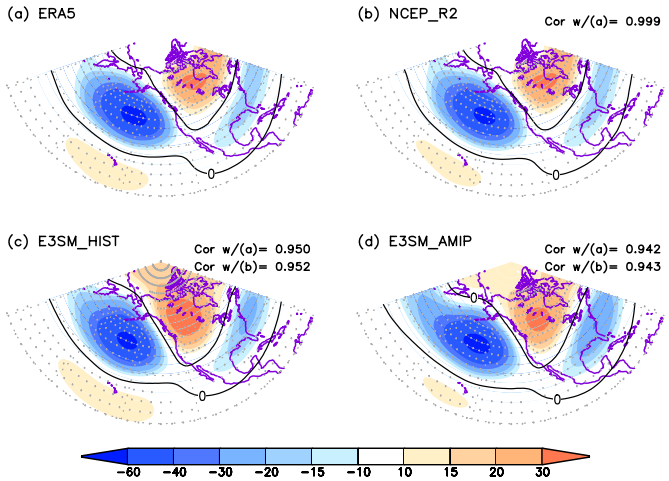
In this study, we evaluate the E3SM's performance in simulating wintertime Pacific North America (PNA) mode. The PNA teleconnection reflects the leading planetary-scale atmospheric mode of variability spanning over the North Pacific basin and North America continent. The variability in PNA can influence the position and strength of the Pacific jet stream and North Pacific storm track, leading to significant impact on winter time climate in North America. PNA, in turn, is strongly influenced by the phases and modes of El Nino Southern Oscillation (ENSO). Considering these connections, we deconstruct the E3SMv1 simulated PNA variability and the influence on North America winter climate in terms of Eastern Pacific El Nino, Central Pacific El Nino, and an internal mode, and evaluate them against observations in the same format. The mechanisms governing the variability of PNA are further investigated.

Definition of PNA index and pattern

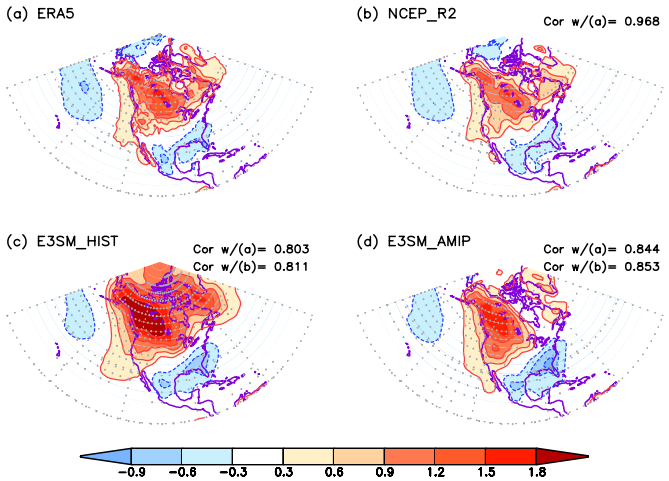
- Monthly PNA index: constructed by the modified pointwise method (Wallace and Gutzler 1981, Allan et al. 2014, Li et al. 2019).
  {Z500A[15º-25ºN, 180º-140ºW] – Z500A[40º-50ºN, 180º-140ºW]+Z500A[45º-60ºN, 125º-105ºW]-Z500A[25º-35ºN, 90º-70ºW]}/4
  *Z500A: normalized monthly mean Z500 anomaly
- Normalized seasonal mean (DJF) PNA index (35 years, 1979-2013) is produced by using average of the monthly PNA index.
- The DJF PNA pattern is derived by regressing the seasonal mean DJF anomalous field (Z500A) onto the normalized DJF total PNA index
  *PNA teleconnection pattern region (10º-90ºN, 180º-30ºW)
- Ensemble mean (EM) : The EM pattern of PNA is computed as the mean of individual patterns in positive phase which are derived by the regression of 500-hPa GPH anomalous field in DJF onto the normalized PNA index from individual members.

PNA pattern and impact of PNA on T2m and PREC over North America

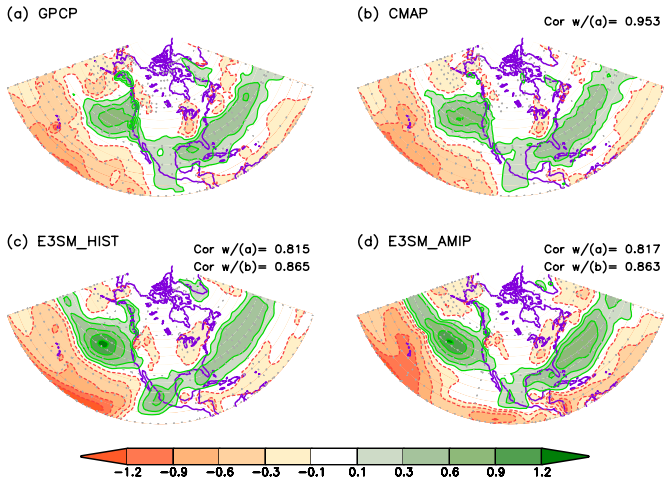
DJF PNA patterns (Z500)



DJF T2m



DJF PREC



- Regression of DJF Z500 (T2m, PREC) anomalies on the standardized DJF total PNA indices (35 years, 1979-2013)
- Gray stippled area: Statistical significance at the 95% confidence level for a two-tailed Student's *t* test
- The ensemble patterns of PNA for E3SM-HIST and AMIP are computed as the mean of individual patterns in positive phase which are derived by the regression of anomaly fields in DJF onto the normalized DJF PNA index from individual members for each simulation.
- Locations of cores of low (high) pressure in simulations over the eastern North Pacific (northern North America) tend to be shifted westward.

Relationship between PNA and ENSO (Forced and internal PNA)

Definition of ENSO index

- We have first carried out the EOF analysis using the DJF SSTA over the tropical Pacific (20S–20N, 110E–70W) from 1979 to 2014, and obtain the first and second (or third) EOF modes of DJF SSTAs as Eastern Pacific (EP)-type and Central Pacific (CP)-type ENSO modes, respectively.

- *EP ENSO index: PC Time series of EOF 1st mode of SSTAs: PC1*
  CP ENSO index: PC Time series of EOF 2nd (or 3rd) mode of SSTAs: PC2 or PC3 (selected by pattern correlation bet. OBS and Model)

Definition of EP/CP ENSO-related and Internal PNA index

To get the partial regression coefficients (b1 and b2) forced by EP ENSO index or CP ENSO index, the multiple regression method is used

- Total PNA index (Y) = b1* EP ENSO index (X1) + b2 * CP ENSO index (X2) + a(0)

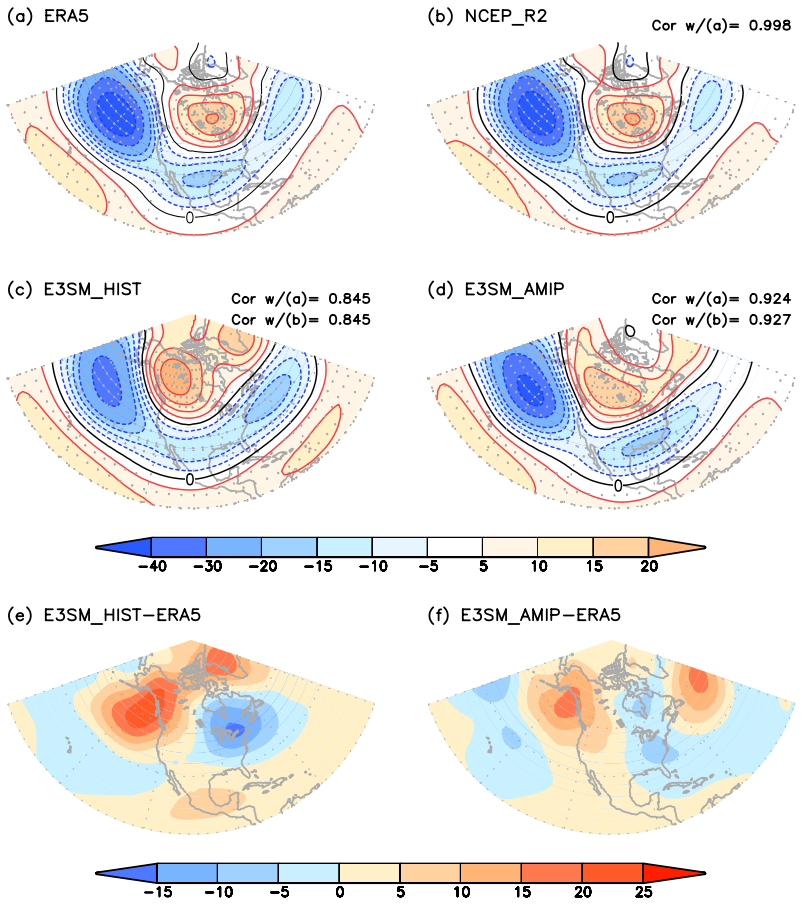
- After getting b1 and b2 from the upper equation,
  *Reconstructed EP ENSO-related PNA index (Y1) is calculated. (Y1 = b1 * EP ENSO index (X1))*
  *Reconstructed CP ENSO-related PNA index (Y2) is calculated. (Y2 = b2 * CP ENSO index (X2))*
  Reconstructed EP and CP ENSO-related PNA index (Y3) is calculated . (Y3 = b1 * EP ENSO index (X1) + b2 * CP ENSO index (X2))
  Reconstructed internal PNA index (Y4) is calculated. (Y4 = Total PNA index (Y) – EP and CP ENSO-related PNA index (Y3))

- Each PNA index is normalized.

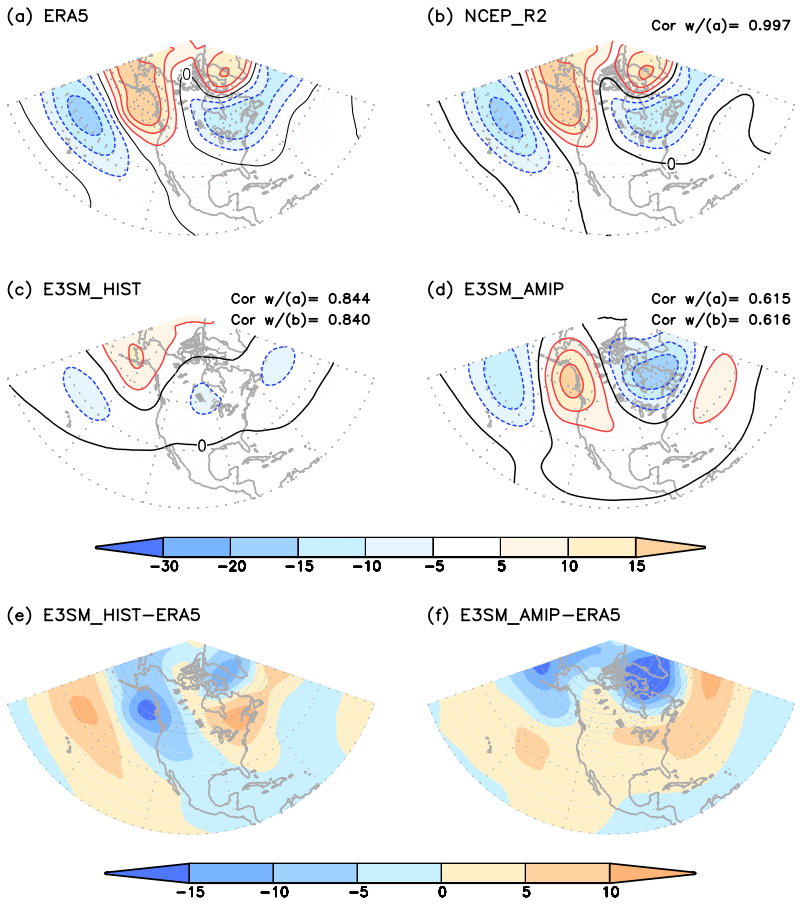
- Regression of Z500A onto normalized PNA indices (EP ENSO-related PNAI, CP ENSO-related PNAI, and Internal PNAI)

Relationship between PNA and ENSO (Forced and internal PNA, Z500)

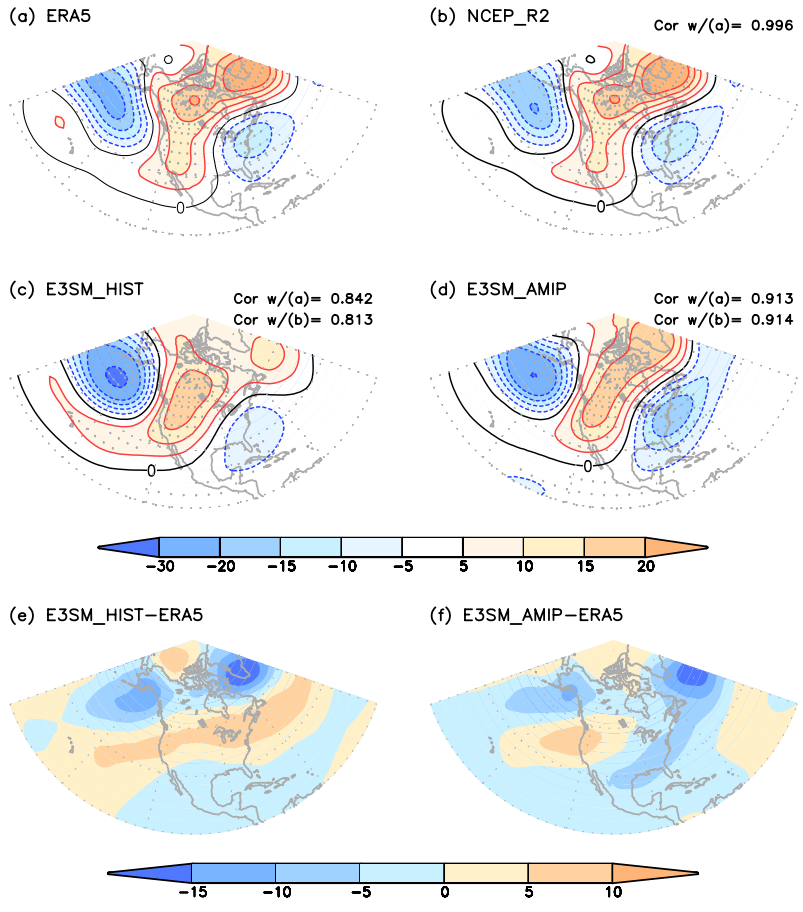
EP ENSO-related PNA



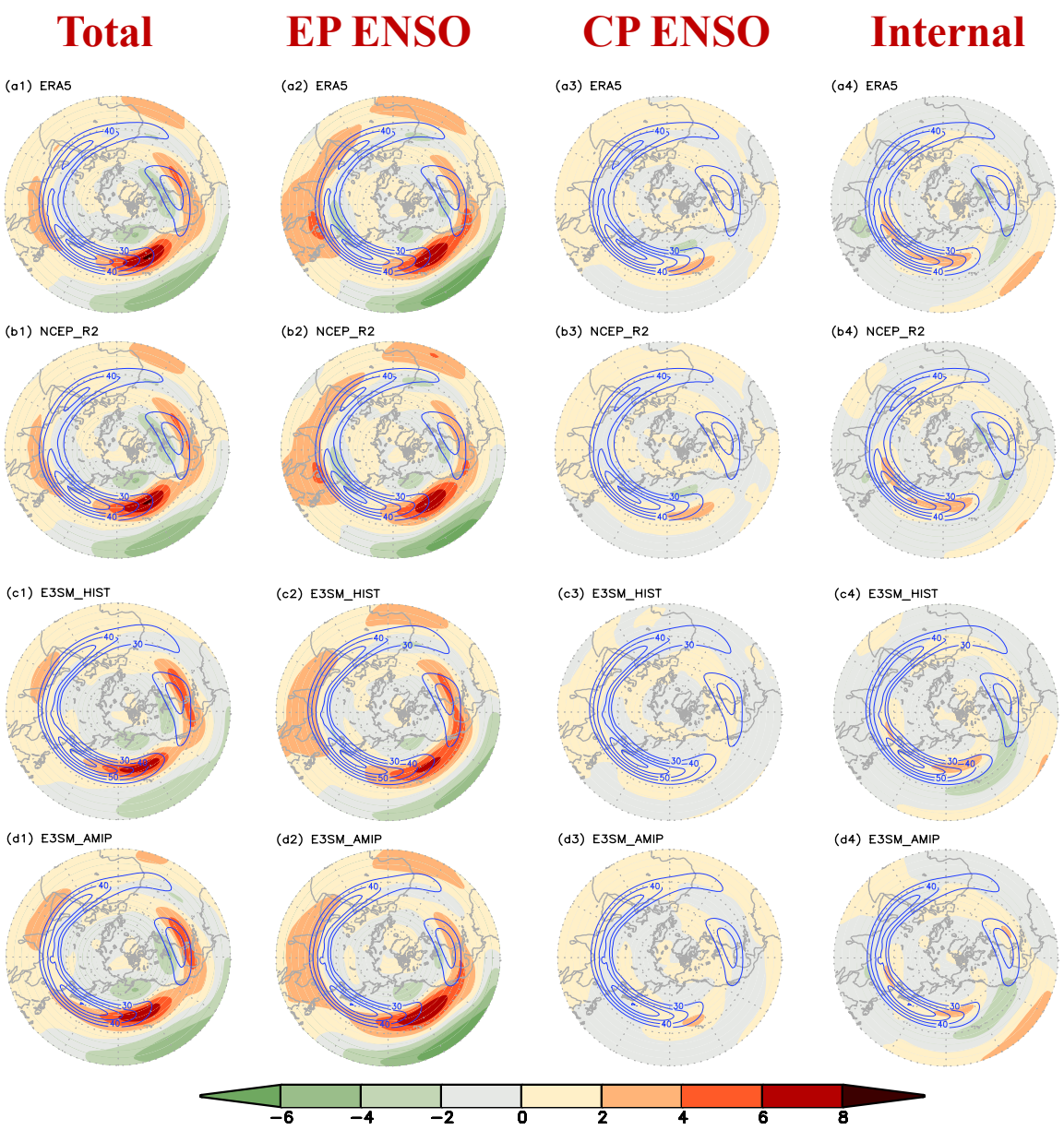
CP ENSO-related PNA



Internal PNA



Relationship between wintertime Jet stream (position and intensity) and PNA



- Climatological DJF U200 (contour, blue, interval is 10 m/s)
- Regressed DJF U200 anomalies (shaded) onto (1) Total PNAI, (2) EP ENSO-related PNAI , (3) CP ENSO-related PNAI, and (4) Internal PNAI

- In the Pacific sectors, the observed regression pattern of DJF U200 anomaly exhibit tripole patterns with anomalies elongated in the zonal direction.
- **Total PNA:** characterized by that an exit region of the extratropical Pacific jet is extended eastward and also by the subtropical North America jet is displaced equatorward of its climatological mean position.
- **EP ENSO-related PNA:** more eastward extension in the extratropical Pacific jet and slightly low intensity in the subtropical North America jet
- **CP ENSO-related PNA:** the exit region of the extratropical Pacific jet is extended southeastward and the subtropical North America jet is displaced slightly poleward
- **Internal PNA:** center locations of tripole patterns move northeastward and their intensities are very low

- Both E3SM-HIST and AMIP simulations show the similar PNA patterns to observation
- **Total PNA:** extension of the extratropical jet in HIST is short compared to AMIP and two observations.
- **EP ENSO-related PNA:** intensity of the Pacific jet in HIST is weak and the subtropical jet is displaced less equatorward
- **CP ENSO-related PNA:** intensity of the Pacific jet in HIST is weaker and its exit region is extended less equatorward compared to observations and AMIP.
- **Internal PNA:** the exit regions of the Pacific jet in both simulations show the northward extension compared to observations.

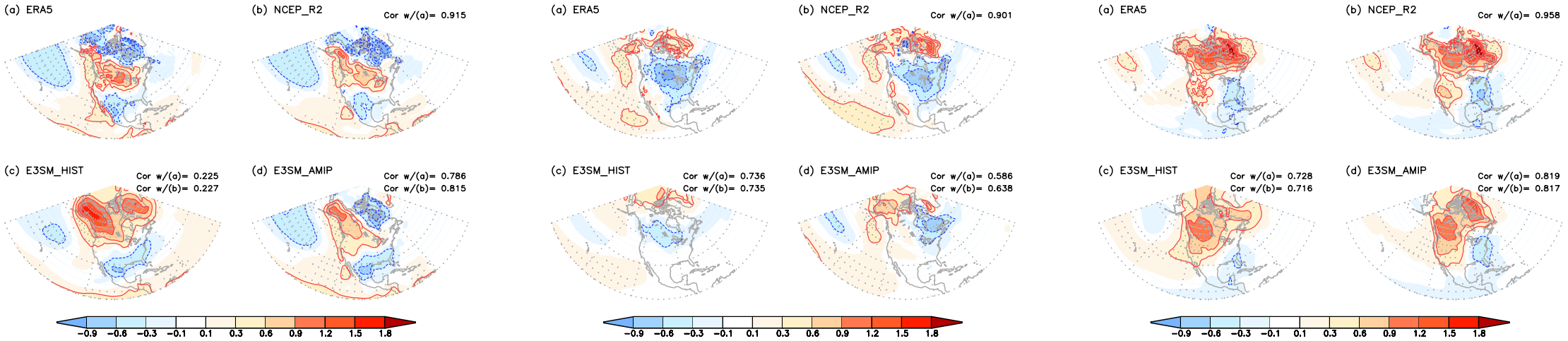
Comparison of T2m and PREC (surface climate) over North America

EP ENSO-related PNA

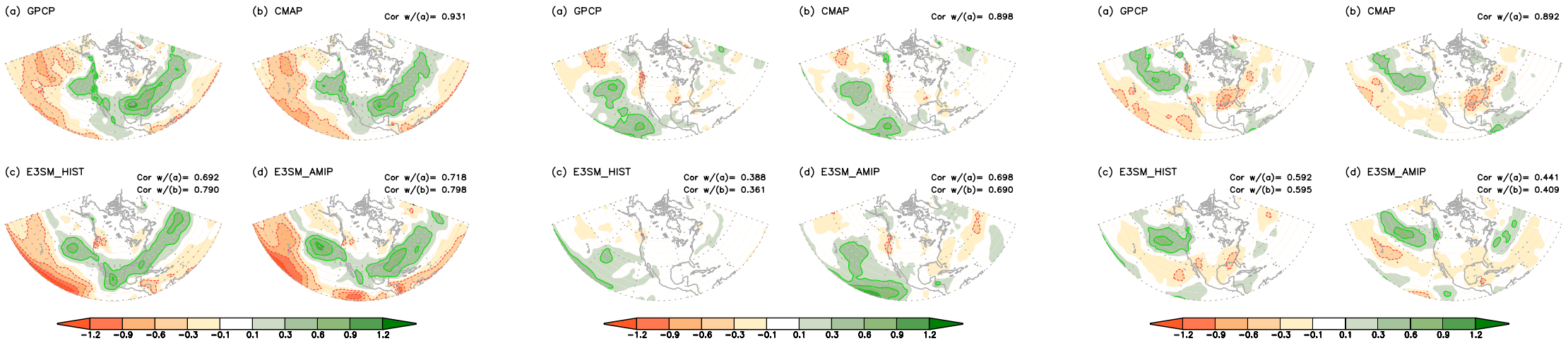
CP ENSO-related PNA

Internal PNA

T2m

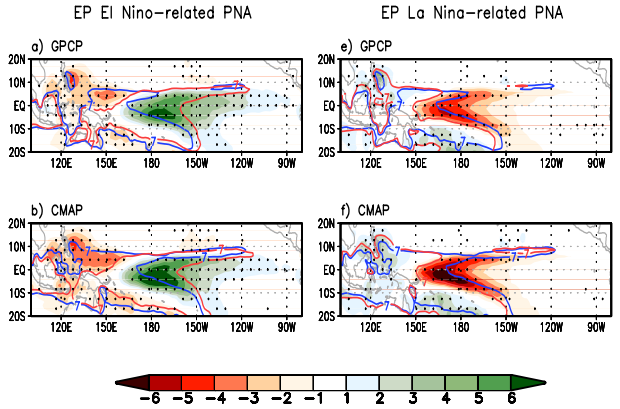


PREC



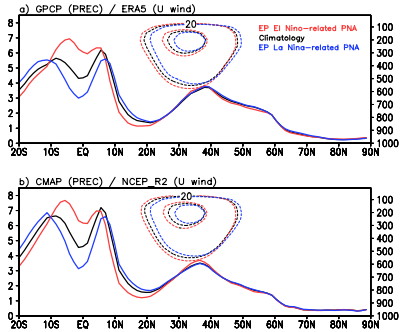
Mechanism of PNA teleconnection driven by the EP and CP ENSO-forced PNA

Rainfall (Tropical Convection)



Blue line (7 mm) is climatology of precipitation
Red line (7 mm) is climatology + composite for each PNA
Shading is composite anomaly for each PNA
Black dots are significant Z test (95%) for composite analysis

Zonal mean of Rainfall and U Wind (Hadley cell and Pacific Jet)



- Solid line: zonal mean (100E-90W) PREC
- Dashed line: zonal mean U wind (int=20 m/s)

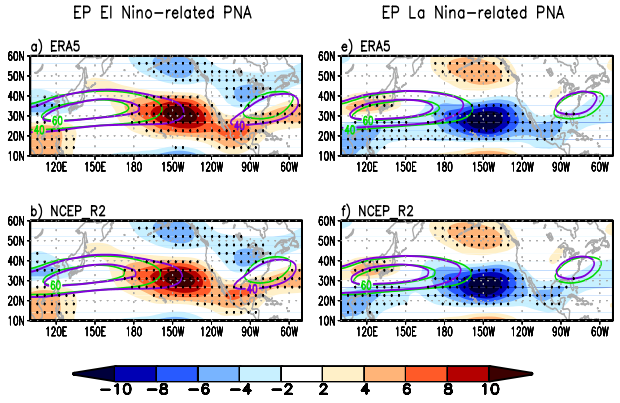
- Subsidence branch of the Hadley circulation using the latitude with minimum zonal mean precipitation in the subtropics (100E-90W)

Equatorward (poleward) shift of Pacific jet stream
: due to strengthening and equatorward contraction (poleward extension) of Hadley cell during EP El Nino (La Nina)-related PNA

OBS EP ENSO PNA

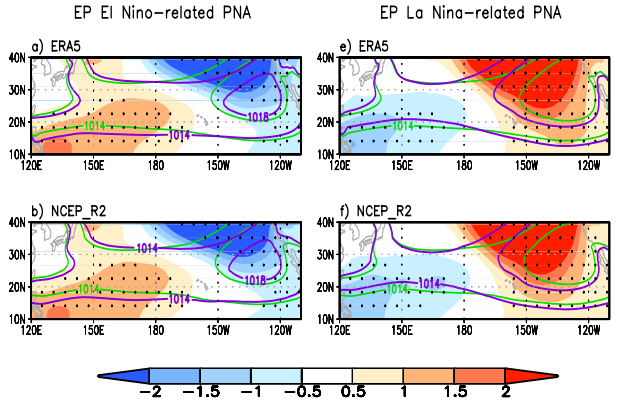
	EP El Nino-related PNA		EP La Nina-related PNA
Equatorial Central Pacific Deep Convection	• Strongly enhanced (near the tropical date line) • Eastward migration • Strengthening and Equatorward contraction of HC		• Strongly suppressed (near the tropical date line) • Westward migration • Weakening and Poleward extension of HC
WNP / ENP Subtropical High	• Slightly enhanced / Strongly weakened • North and Southward expansion / Contraction • Weakly equatorward / Strongly Equatorward • Eastward extension due to the weakened ENPSH		• Slightly suppressed / Strongly enhanced • Northward contraction / North and southward expansion • Weakly poleward / Strongly Poleward • Westward retraction due to the enhanced ENPSH
Pacific Jet	• Eastward expansion • Strongly equatorward shift		• Westward retraction • Strongly poleward shift
Aleutian Low	• Pressure deepens • Strongly enhanced • Southeastward shift		• Pressure goes up • Strongly suppressed • Northwestward shift
PNA teleconnection	• N. NA High pressure develops • SE US Low pressure prevails • Enhanced Positive PNA		• N. NA High pressure drops • SE US High pressure prevails • Enhanced Negative PNA

U200 (Pacific Jet)



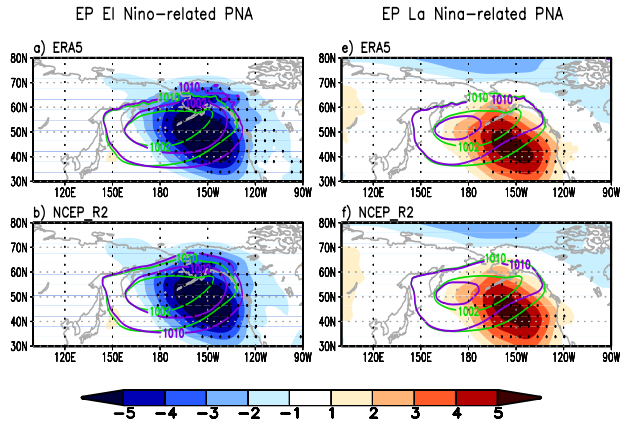
Green line (40, 60 m/s) is climatology of U200 (Pacific Jet)
Purple line (40, 60 m/s) is climatology + composite for each PNA

SLP (WNPSH/ENPSH)



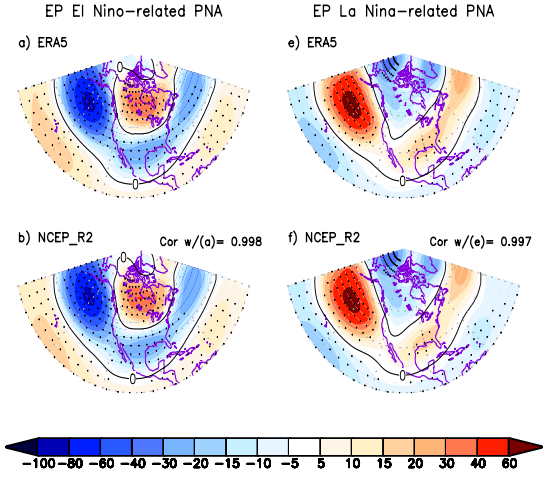
Green line (1014, 1018 hPa) is climatology of SLP (Subtropical High)
Purple line (1014, 1018 hPa) is climatology + composite for each PNA

SLP (Aleutian Low)



Green line (1002, 1010 hPa) is climatology of SLP (Aleutian Low)
Purple line (1002, 1010 hPa) is climatology + composite for each PNA

Z500 (PNA related to EP ENSO)



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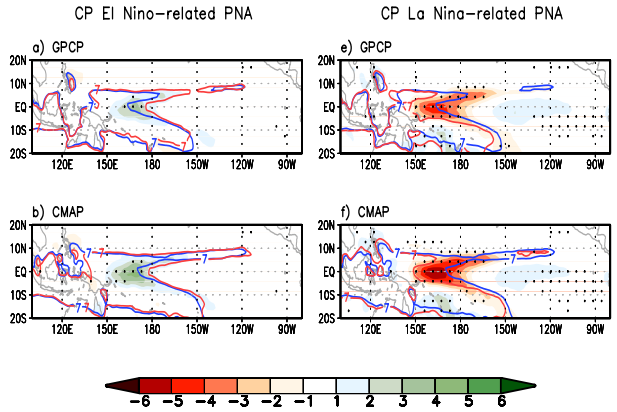

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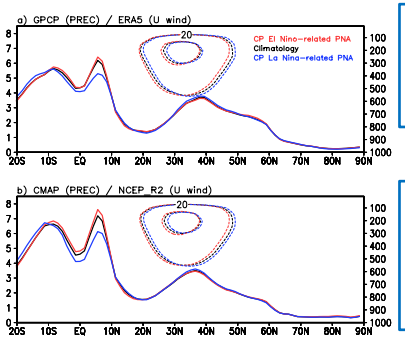


- Solid line: zonal mean (100E-90W) PREC
- Dashed line: zonal mean U wind (int=20 m/s)

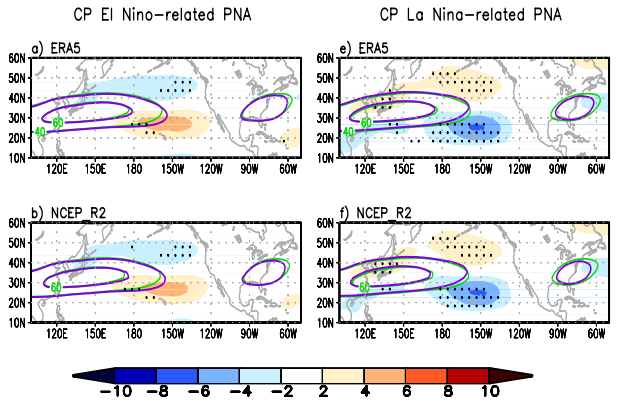
- Subsidence branch of the Hadley circulation using the latitude with minimum zonal mean precipitation in the subtropics (100E-90W)

Negligible in equatorward (poleward) shift of Pacific jet
: due to slight changes in strengthening and equatorward contraction (poleward extension) of Hadley cell during CP El Nino (La Nina)-related PNA

OBS CP ENSO PNA

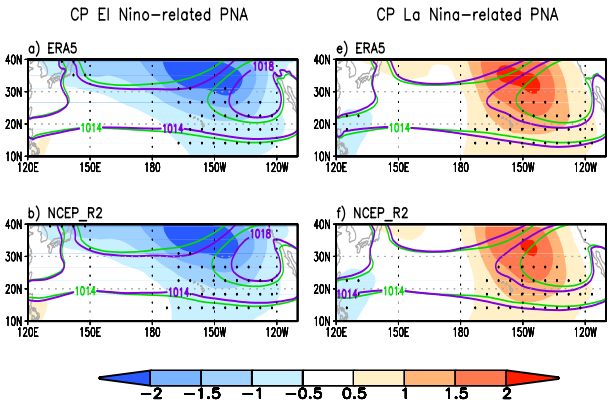
	CP El Nino-related PNA	CP La Nina-related PNA
Equatorial Western Pacific Deep Convection	• Weakly developed (west of the tropical date line) • Weak Eastward migration • Slight changes in HC intensity and shift	• Weakly suppressed (west of the tropical date line) • Weak Westward migration • Slight changes in HC intensity and shift
WNP / ENP Subtropical High	• Weakly weakened • No change in center of action / Slightly equatorward of center • Slightly Southward contraction of northern part / Contraction	• Weakly enhanced • No change in center of action / Slightly poleward of center • Northward expansion of northern part / Expansion
Pacific Jet	• Weak in eastward expansion • Negligible in equatorward shift	• Weak in westward retraction • Negligible in poleward shift
Aleutian Low	• Pressure weakly deepens • Weakly enhanced • Equatorward shift due to weakly suppressed ENPSH	• Pressure weakly goes up • Weakly suppressed • Poleward shift due to weakly enhanced ENPSH
PNA teleconnection	• N. NA High pressure weakly develops • S. US Low pressure weakly prevails • Weakened Positive PNA	• W. NA High pressure weakly drops • E. NA High pressure weakly prevails • Weakened Negative PNA

U200 (Pacific Jet)



Green line (40, 60 m/s) is climatology of U200 (Pacific Jet)
Purple line (40, 60 m/s) is climatology + composite for each PNA

SLP (WNPSH/ENPSH)



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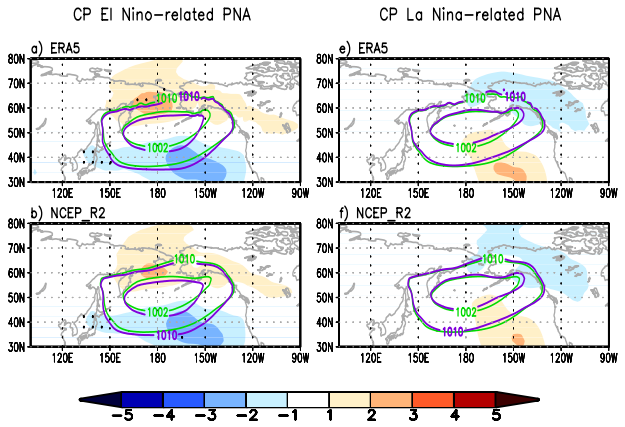

Green line (1002, 1010 hPa) is climatology of SLP (Aleutian Low)
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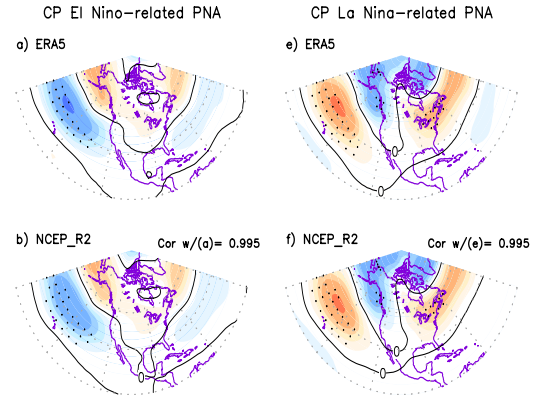
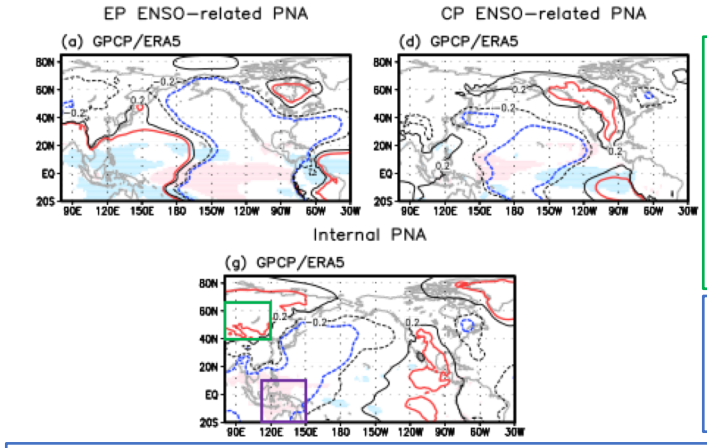
Z500 (PNA related to CP ENSO)



Mechanism of PNA teleconnection driven by the internal PNA

TCC between SLP (contour), PREC (shading) & PNA indices

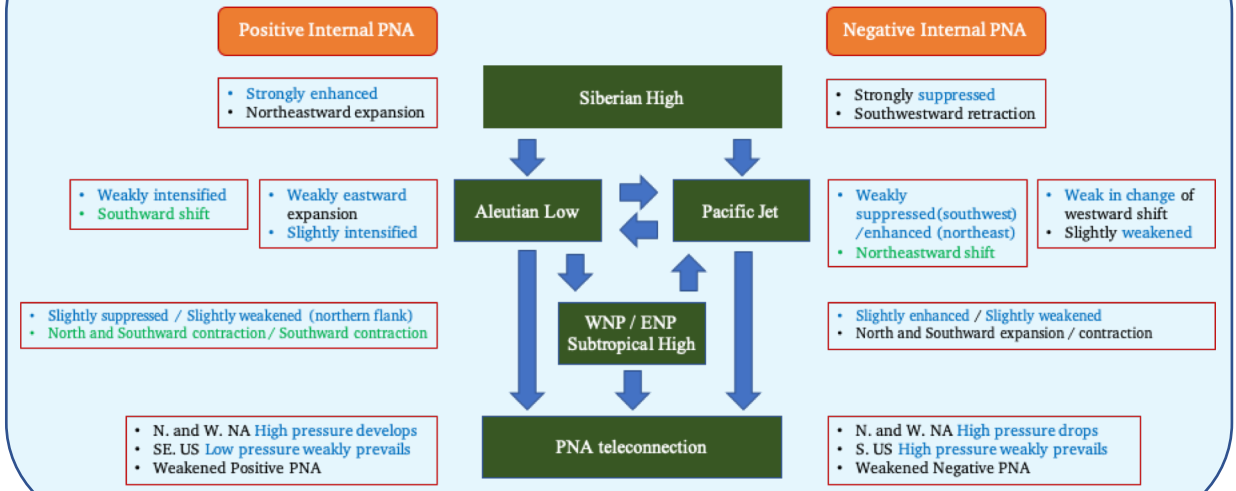


- Evidences showing a close relationship between Siberian High and internal PNA.
- In observation, there is high correlation between SLP and Int. PNA index over Siberian region.
- Simulated internal PNA patterns show the similar patterns to observation over the Siberian region, even if the correlation values are a little bit lower than observation.

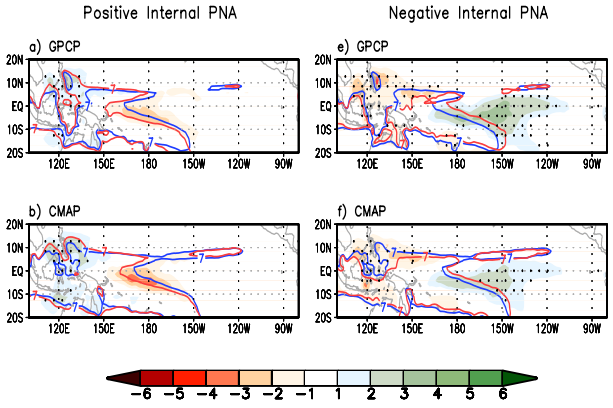
- Lines (shadings): significant at 95% confidence level for a two-tailed t-test.
- Red: positive, Blue: negative, Black lines: +/- 0.2 lines
- PREC: TCC over 20S-20N, SLP: TCC over 20S-85N

- Siberian High Index (SHI): winter (DJF) SLP averaged over the area 40°–65°N, 80°–120°E
- Western tropical Pacific deep convection index (WTPCI): winter (DJF) PREC averaged over the area 20°S–10°N, 110°–150°E
- Internal PNAI has a very close relationship with SHI (TCC=0.504) and WTPCI (TCC=0.512), respectively.

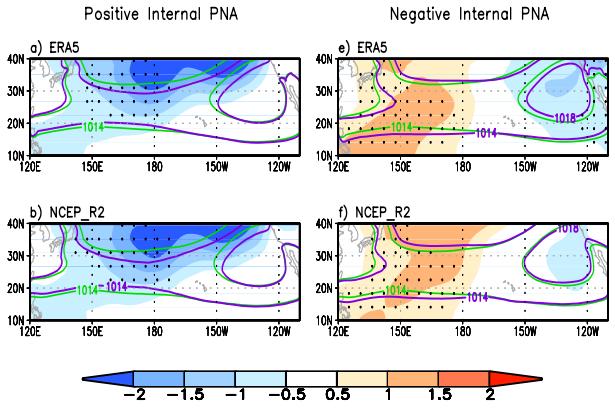
OBS Internal PNA



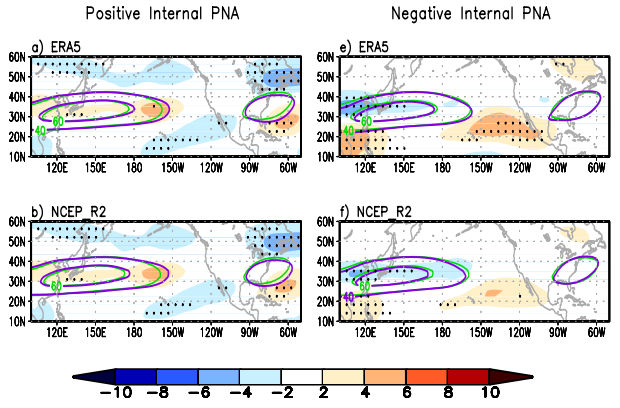
Rainfall (Tropical Convection)



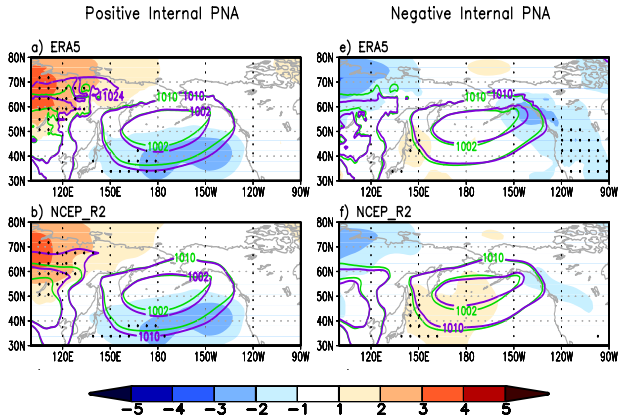
SLP (WNPSH/ENPSH)



U200 (Pacific Jet)



SLP (Aleutian Low, Siberian High)



- In terms of the strengthening of the WNPSH, it matches much more with the intensity variability of deep convection in the central Pacific that is less relevant to internal PNA rather than that in the western Pacific. For the phase shift of the Pacific jet stream, however, it tends to be inconsistent with the migration of tropical deep convection in the central Pacific. In addition, we have examined the relationship between PNA teleconnection patterns of Z500 regressed by forcings, such as WTPCI, SHI and internal PNAI. It is found that the regressed patterns by SHI and internal PNAI are closely connected (PCC=0.67 for ERA5 and 0.57 for NCEP_R2) in observation, while the interrelationship (PCC=-0.23 for ERA5 and -0.21 for NCEP_R2) between the patterns regressed by WTPCI and internal PNAI tends to be very lower (Figure not shown). In short, the impact of tropical deep convection in the western and central Pacific on the internal PNA seems to be insufficient to interpret that it affects the extra-tropical teleconnection.