

Influence of Three Tropical Oceans on Western North Pacific Anticyclone Strengthening under Global Warming

Zhiyuan Lu^{1,2}, Chunzai Wang^{1,3,4*}

1. State Key Laboratory of Tropical Oceanography, South China Sea Institute of Oceanology, Chinese Academy of Sciences, Guangzhou, China
2. University of Chinese Academy of Sciences, Beijing, China
3. Global Ocean and Climate Research Center, South China Sea Institute of Oceanology, Chinese Academy of Sciences, Guangzhou, China
4. Guangdong Key Laboratory of Ocean Remote Sensing, South China Sea Institute of Oceanology, Chinese Academy of Sciences, Guangzhou, China

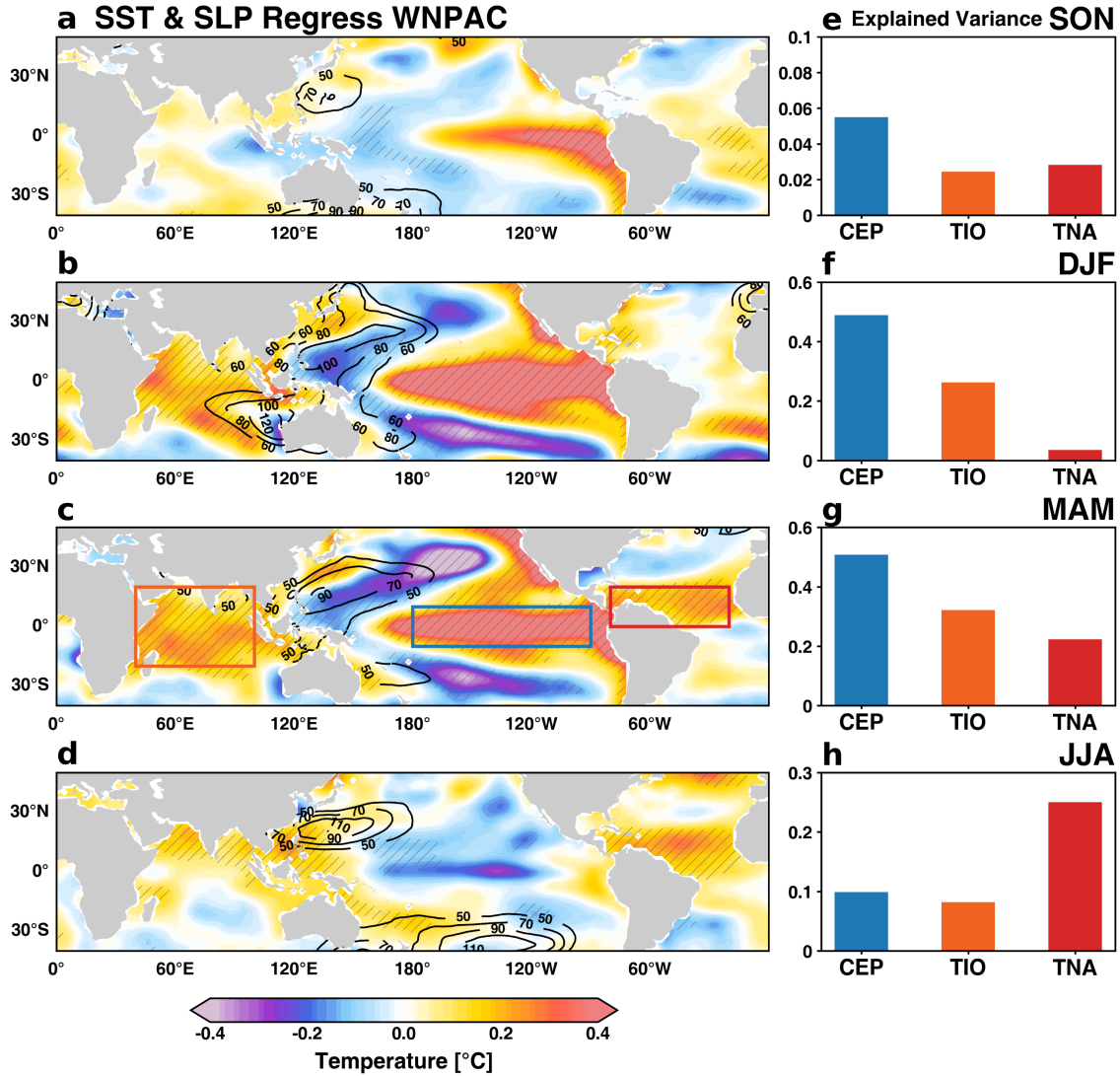
Corresponding authors:

Chunzai Wang (cwang@scsio.ac.cn)

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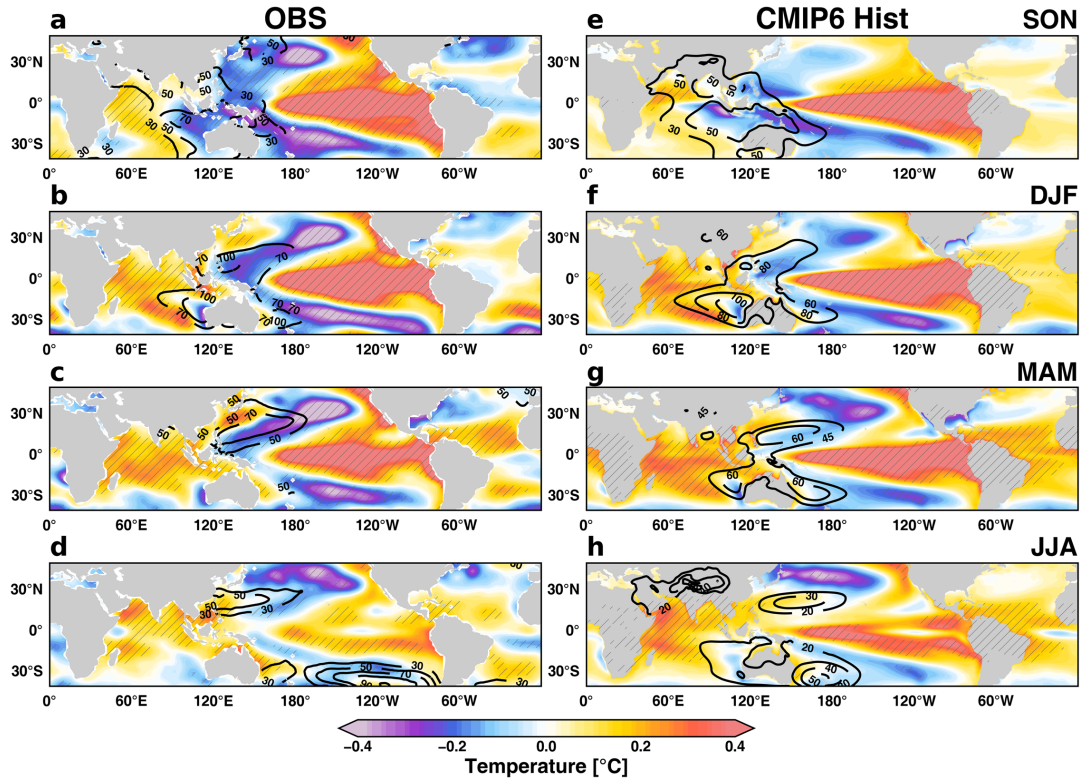
Supplementary Figure 1 to 6

Supplementary Table 1

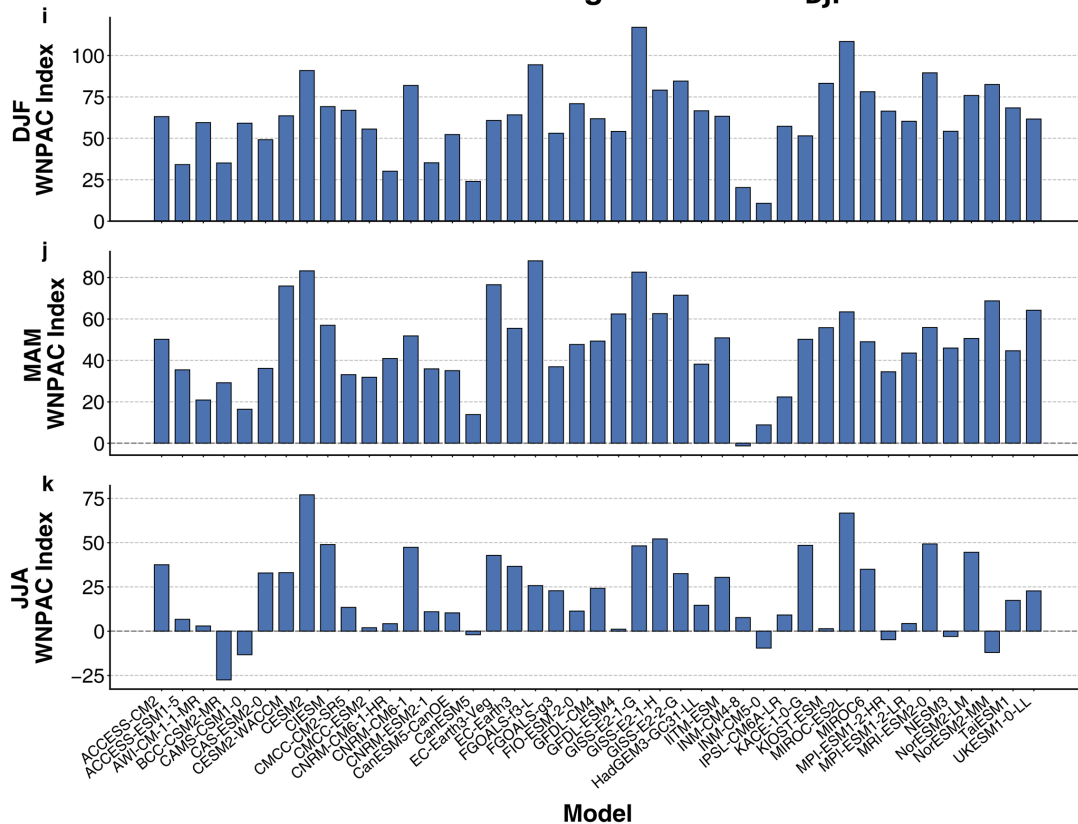


Supplementary Figure 1. Observational WNPAC and Associated SST Anomalies (1979–2023). **a-d** Observed SLP (contours) and SST (shading) anomalies regressed onto the observational WNPAC index for (a) SON, (b) DJF, (c) MAM and (d) JJA. Hatched regions denote SST correlations statistically significant at the 95% confidence level. **e-h** Relative contributions of the three oceans to WNPAC variability during their most influential seasons. Data span the period 1979–2023. Patches indicate the regions within which CEP, TIO and TNA indices are computed.

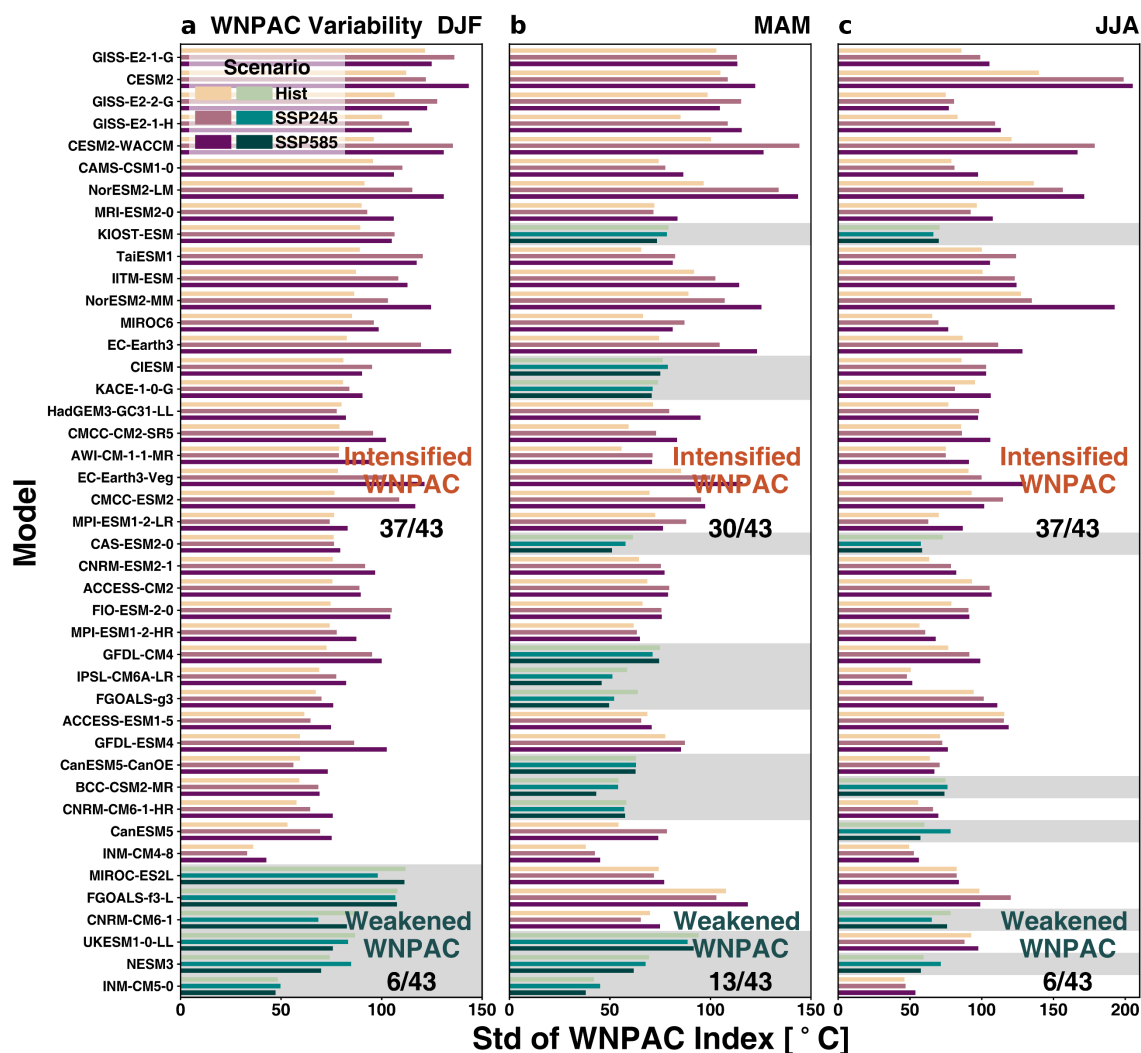
SST & SLP Regress NINO34_{DJF}



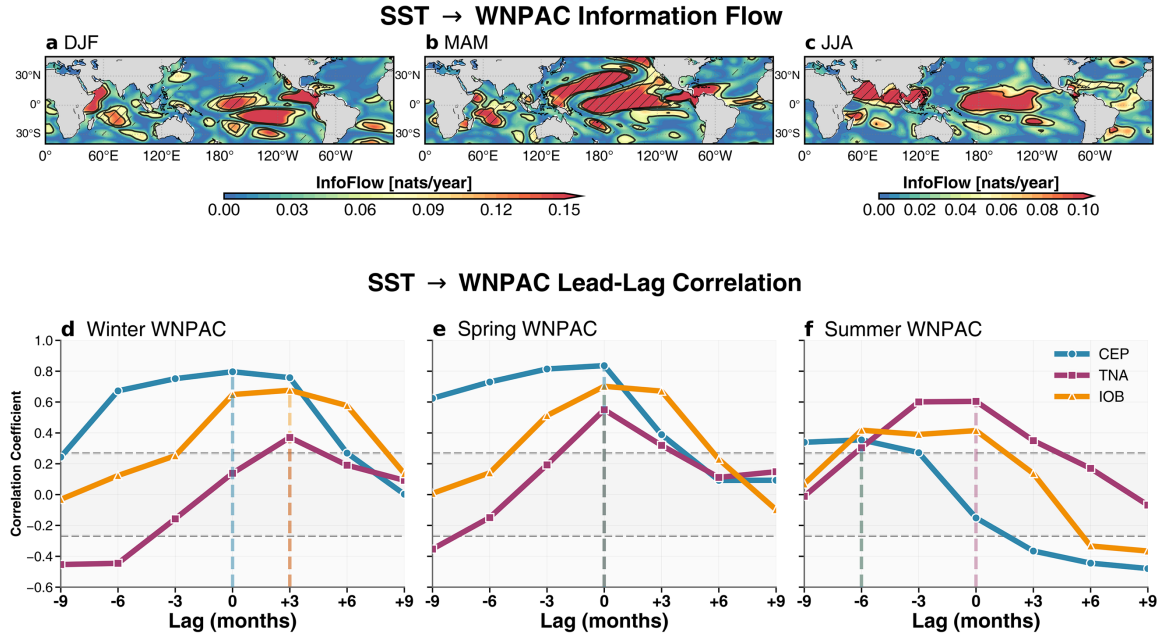
WNPAC Index Regress NINO3.4_{DJF}



Supplementary Figure 2. CMIP6 Model Evaluation of WNPAC. **a-d** Observed regressions of SST (shading, °C) and SLP (contours, hPa) anomalies onto DJF Niño3.4 index for the seasons **(a)** SON, **(b)** DJF, **(c)** MAM, and **(d)** JJA, respectively. **e-h** Same as a–d but for CMIP6 historical MME. Regions with ensemble agreement over 60% are masked in gray. **i-k** Regression coefficients of WNPAC index onto DJF Niño3.4 index for each individual CMIP6 model in **(i)** DJF, **(j)** MAM, and **(k)** JJA. Bars represent the amplitude of ENSO-forced WNPAC response in each model, with consistent positive values across most models across three seasons, confirming the ensemble’s ability to represent the observed teleconnection.

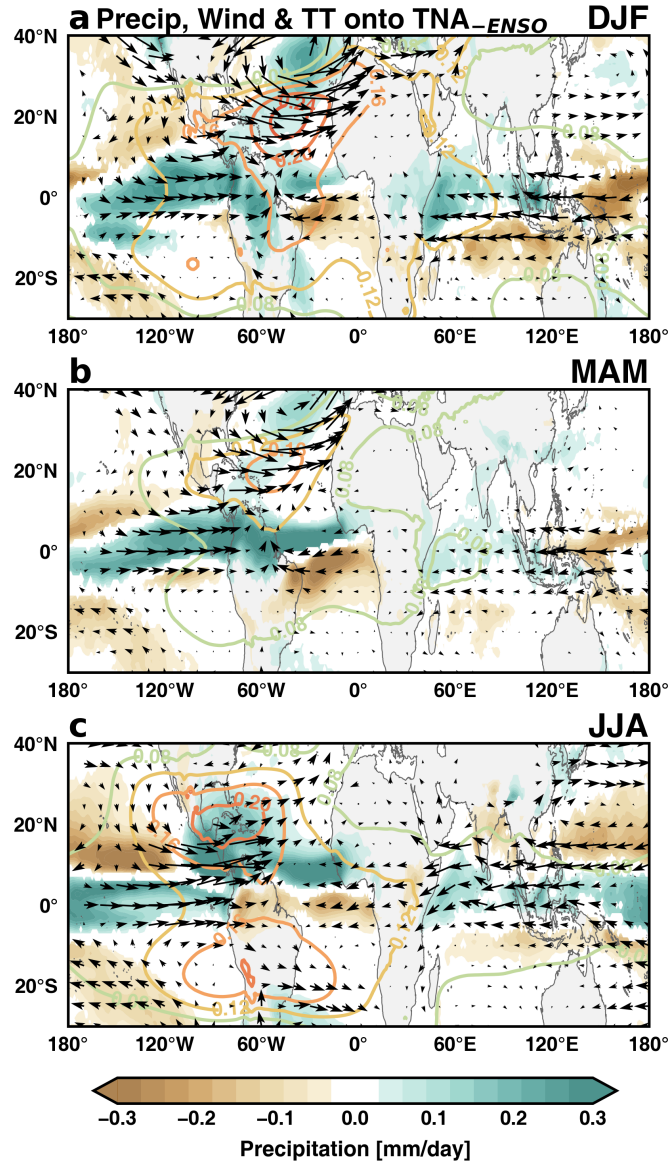


Supplementary Figure 3. Projected Changes in WNPAC Variability Under Global Warming Based on 43 CMIP6 Models. Historical WNPAC variability (1900–2014) is quantified as the standard deviation of WNPAC index under historical forcing. Future variability (2015–2099) is derived from the standard deviation under SSP245 and SSP585 scenarios. Models are classified as exhibiting intensified (warm-colored lines) or weakened (green lines) WNPAC variability based on increased or decreased standard deviations under SSP585 relative to historical forcing. Results reflect a multi-model ensemble analysis, highlighting inter-model consistency in projected changes.



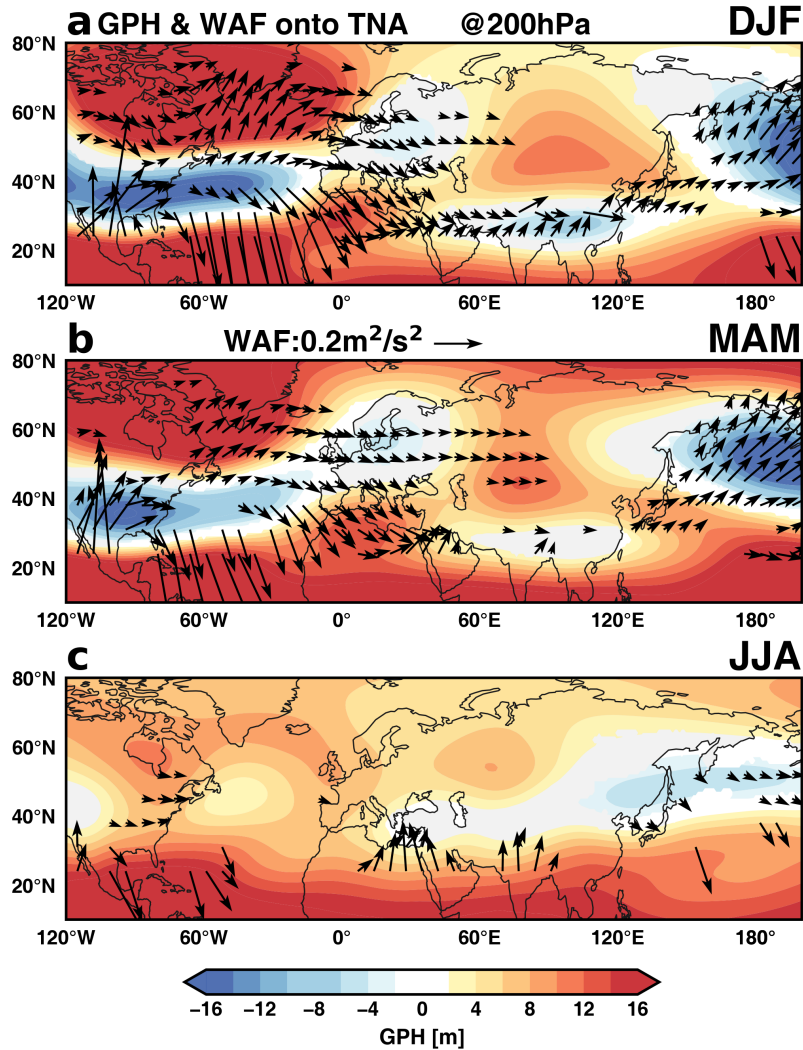
Supplementary Figure 4. Identification of Optimal Seasonal SST–WNPAC Relationships based on Information Flow and Lead–lag Correlation Analyses. **a–c** Seasonal information flow from SST anomalies to WNPAC index, measured using Liang-Kleeman information flow framework (see Methods). Significance (hatches) is tested using a Z-test ($p < 0.05$). Yellow shading indicates stronger directional influence. **d–f** Lead–lag correlation coefficients between WNPAC index and leading SST modes of CEP (blue), TNA (orange), and TIO (purple). Dashed vertical lines indicate peak correlation timing for each basin.

SSP585



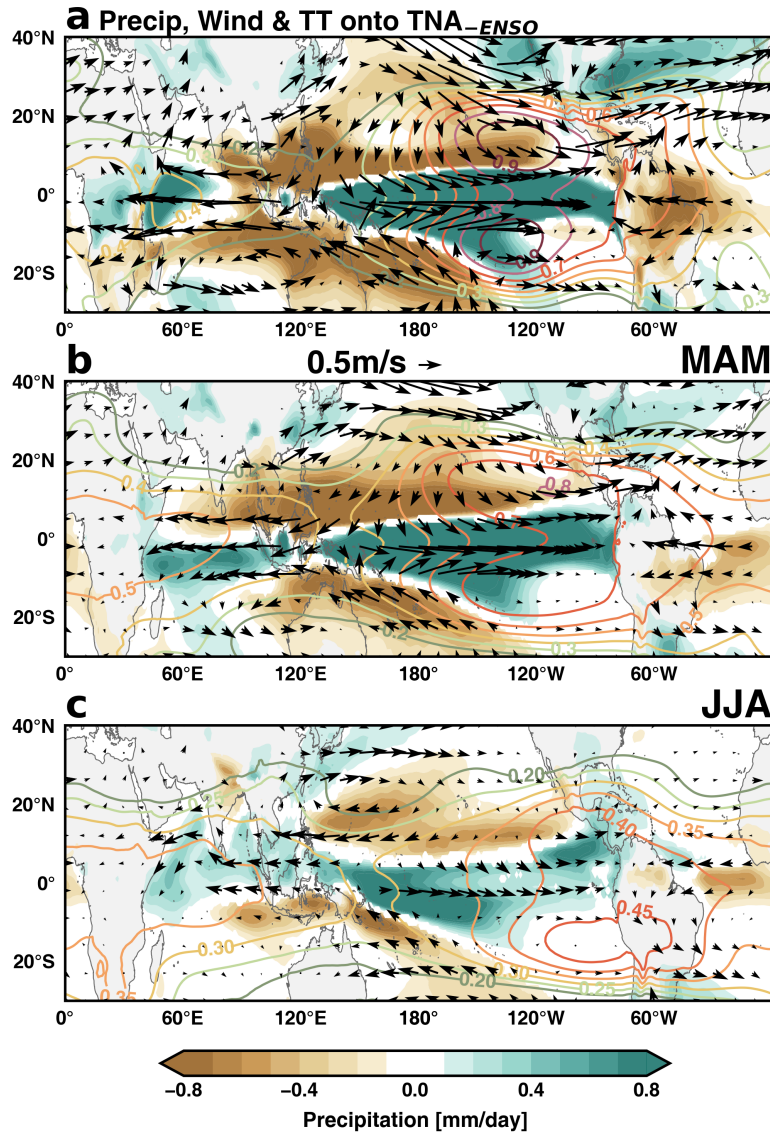
Supplementary Figure 5. The Atlantic Ocean’s ENSO-Independent Influence on Intensified via Equatorial Waves under SSP585 Forcing. Partial regression patterns of precipitation (shading; units: mm day⁻¹), 850 hPa horizontal winds (vector; units: m s⁻¹), and tropospheric temperature (TT; contour; units: °C) onto TNA index, after removing ENSO effects, for (a) winter, (b) spring, and (c) summer under SSP585 scenario forcing. Data are shown only in regions where more than 60% of models agree on the sign of regression.

SSP585

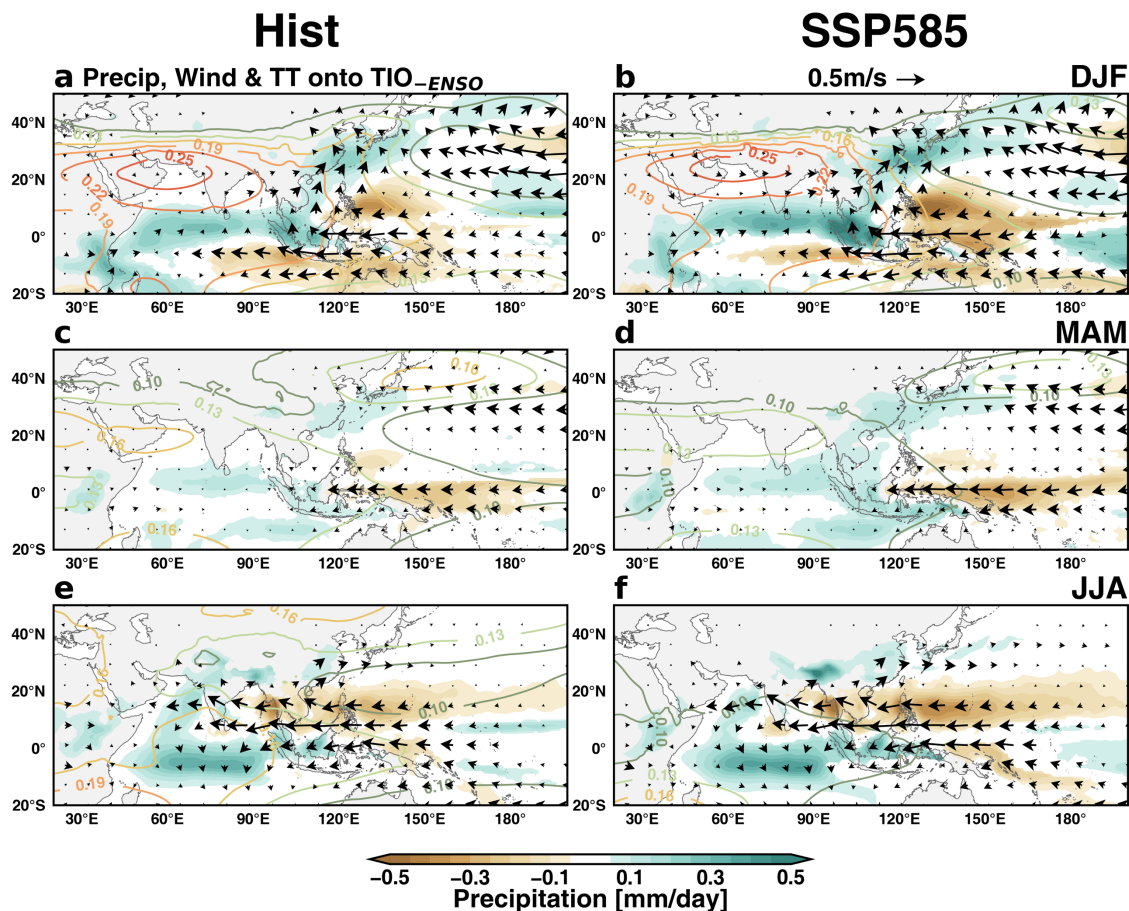


Supplementary Figure 6. The Atlantic Ocean's Influence on Intensified WNPAC via Quasi-stationary Rossby Wave Train under SSP585 Forcing. Regression patterns of 200hPa geopotential height (GPH; shading; units: m) and horizontal wave activity flux (vectors; units: $\text{m}^2 \text{s}^{-2}$) onto TNA index across all three seasons under SSP585 scenario forcing. Data are shown only in regions where more than 60% of models agree on the sign of regression.

SSP585



Supplementary Figure 7. The Pacific Ocean's Influence on Intensified WNPAC Under SSP585 Forcing. Regression patterns of precipitation (shading; units: mm day⁻¹), 850 hPa horizontal winds (vectors; units: m s⁻¹), and tropospheric temperature (TT; contours; units: °C) onto CEP index across all three seasons under SSP585 scenario forcing. Data are shown only in regions where more than 60% of models agree on the sign of regression.



Supplementary Figure 8. The Indian Ocean's ENSO-Independent Influence on Intensified WNPAC via ENSO-Independent Tropical Pathways Under Historical and SSP585 Forcing. Partial regression patterns of precipitation (shading; units: mm day^{-1}), 850 hPa horizontal winds (vectors; units: m s^{-1}), and TT (contours; units: $^{\circ}\text{C}$) onto the Tropical Indian Ocean (TIO) index, after removing ENSO effects across all three seasons. (a, c, e) Historical simulations (1900–2014); (b, d, f) SSP585 projections (2015–2099). Data are shown only in regions where more than 60% of models agree on the sign of regression.

Supplementary Table 1. Introduction of CMIP6 models. Name, institution, realization and spatial resolution of each CMIP6 model used in this study are shown.

Name	Institution	Realization	Resolution
ACCESS-CM2	CSIRO-ARCCSS-BoM	rlilp1fl	$92^{\circ} \times 144^{\circ}$
ACCESS-ESM1-5	CSIRO	rlilp1fl	$192^{\circ} \times 145^{\circ}$
AWI-CM-1-1-MR	AWI	rlilp1fl	$384^{\circ} \times 192^{\circ}$
BCC-CSM2-MR	BCC	rlilp1fl	$320^{\circ} \times 160^{\circ}$
CAMS-CSM1-0	CAMS	rlilp1fl	$320^{\circ} \times 160^{\circ}$
CanESM5	CCCma	rlilp1fl	$128^{\circ} \times 64^{\circ}$
CanESM5-CanOE	CCCma	rlilp2fl	$128^{\circ} \times 64^{\circ}$
CAS-ESM2-0	CAS	rlilp1fl	$256^{\circ} \times 128^{\circ}$
CESM2	NCAR	rlilp1fl	$288^{\circ} \times 192^{\circ}$
CESM2-WACCM	NCAR	rlilp1fl	$288^{\circ} \times 192^{\circ}$
CIESM	THU	rlilp1fl	$288^{\circ} \times 192^{\circ}$
CMCC-CM2-SR5	CMCC	rlilp1fl	$288^{\circ} \times 192^{\circ}$
CMCC-ESM2	CMCC	rlilp1fl	$288^{\circ} \times 192^{\circ}$
CNRM-CM6-1	CNRM-CERFACS	rlilp1f2	$128^{\circ} \times 64^{\circ}$
CNRM-CM6-1-HR	CNRM-CERFACS	rlilp1f2	$360^{\circ} \times 180^{\circ}$
CNRM-ESM2-1	CNRM-CERFACS	rlilp1f2	$128^{\circ} \times 64^{\circ}$
EC-Earth3	EC-Earth-Consortium	rlilp1fl	$512^{\circ} \times 256^{\circ}$
EC-Earth3-Veg	EC-Earth-Consortium	rlilp1fl	$512^{\circ} \times 256^{\circ}$
FGOALS-f3-L	CAS	rlilp1fl	$360^{\circ} \times 180^{\circ}$
FGOALS-g3	CAS	rlilp1fl	$180^{\circ} \times 90^{\circ}$
FIO-ESM-2-0	FIO-QLNM	rlilp1fl	$192^{\circ} \times 288^{\circ}$
GFDL-CM4	NOAA-GFDL	rlilp1fl	$360^{\circ} \times 180^{\circ}$
GFDL-ESM4	NOAA-GFDL	rlilp1fl	$360^{\circ} \times 180^{\circ}$
GISS-E2-1-G	NASA-GISS	rlilp1f2	$144^{\circ} \times 90^{\circ}$
GISS-E2-1-H	NASA-GISS	rlilp1f2	$144^{\circ} \times 90^{\circ}$
GISS-E2-2-G	NASA-GISS	rlilp3fl	$90^{\circ} \times 90^{\circ}$
HadGEM3-GC31-LL	MOHC	rlilp1f3	$192^{\circ} \times 144^{\circ}$

IITM-ESM	CCCR-IITM	rlilp1f1	192° × 94°
INM-CM4-8	INM	rlilp1f1	180° × 120°
INM-CM5-0	INM	rlilp1f1	180° × 120°
IPSL-CM6A-LR	IPSL	rlilp1f1	144° × 143°
KACE-1-0-G	NIMS-KMA	rlilp1f1	192° × 144°
KIOST-ESM	KIOST	rlilp1f1	192° × 96°
MIROC-ES2L	MIROC	rlilp1f2	128° × 64°
MIROC6	MIROC	rlilp1f1	256° × 128°
MPI-ESM1-2-HR	MPI-M	rlilp1f1	384° × 192°
MPI-ESM1-2-LR	MPI-M	rlilp1f1	192° × 96°
MRI-ESM2-0	MRI	rlilp1f1	320° × 160°
NESM3	NUIST	rlilp1f1	192° × 96°
NorESM1-LM	NCC	rlilp1f1	144° × 96°
NorESM2-MM	NCC	rlilp1f1	288° × 192°
TaiESM1	AS-RCEC	rlilp1f1	288° × 192°
UKESM1-0-LL	MOHC	rlilp1f2	192° × 144°