



# Future Change in Tropical Cyclone Activity over the Western North Pacific in CORDEX-East Asia Multi-RCMs Forced by HadGEM2-AO

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## Introduction

- **Tropical cyclones (TCs) are considered to be the most destructive natural hazards in East Asia due to significant casualties and property damages.**
- **Many previous studies have examined the change in TC activity induced by global warming using general circulation models (GCMs).**
- **The regional climate model (RCM), a technique of regional dynamical downscaling, shows more realistic TC genesis frequency or TC structure than the GCM (Emanuel et al. 2008; Bender et al. 2010; Mendelsohn et al. 2010). However, RCMs have suffered from the mismatch of physics between RCM and GCM, the lack of feedback of the simulated storm to the global climate system, and inherent uncertainties and systematic error induced by a single RCM (Emanuel 2013).**
- **Nevertheless, the future change in TC activities over the WNP has been analyzed by RCM because of its specialized regional feature and high-resolution projection.**
- **In this study, the future changes and TC activity over the WNP under the representative concentration pathway (RCP) 8.5 scenario were projected using four models (RegCM, SNURCM, WRF, and GRIMs) that participated in the CORDEX-East Asia project.**

## Data and methodology

### Data

- The TC best track data from the Regional Specialized Meteorological Centers (RSMC) Tokyo–Typhoon Center were obtained for the period of 1980–2005.
- The analysis was focused on TCs that formed from June to November (JJASON), since most TCs over the WNP (around 85% of the total annual TCs) tend to occur during the period.
- To evaluate the performance of the RCMs, simulated atmospheric fields were compared with ERA-Interim (Dee et al. 2011).

# Data and methodology

## CORDEX-East Asia models

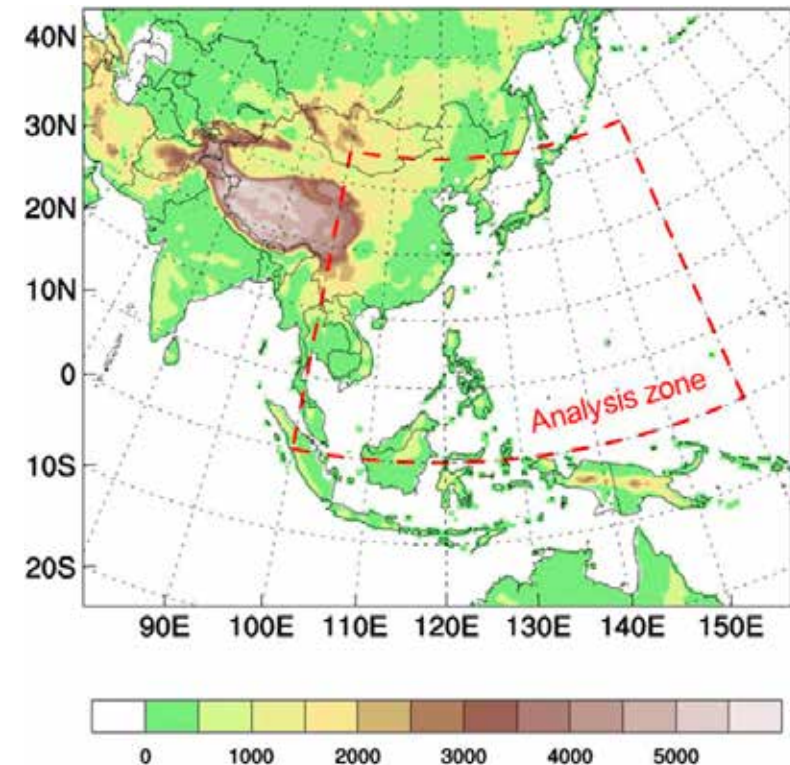
The configuration of the RCMs used in this study.

	<b>RegCM</b>	<b>SNURCM</b>	<b>WRF</b>	<b>GRIMs</b>
<b>Institute</b>	Kongju National University	Seoul National University	Seoul National University	Yonsei University
<b>Dynamics framework</b>	Hydrostatic	Nonhydrostatic	Nonhydrostatic	Hydrostatic
<b>Projection, resolution</b>	Lambert conformal, 50km	Lambert conformal, 50km	Lambert conformal, 50km	Mercator, 50km
<b>Vertical levels</b>	18	24	27	22
<b>Convection</b>	Emanuel (1991)	Kain (2004)	Kain (2004)	Hong and Pan (1998)
<b>PBL</b>	Holtslag et al. (1990)	Hong et al, (2006)	Hong et al, (2006)	Hong et al, (2006)
<b>Spectral nudging</b>	Yes (full wind nudging)	Yes (full wind nudging)	Yes (full wind nudging)	Yes (rotational wind nudging only)
<b>Reference</b>	Giorgi et al. (2012)	Lee et al. (2004)	Skamarock et al. (2008)	Hong et al. (2013)

## Data and methodology

- Under the CORDEX-East Asia framework, two periods are defined to assess the RCMs' abilities to reproduce present climate and estimate the future regional climate change under the RCP8.5 scenario: 1979–2005 for the present climate and 2006–50 for the future climate.
- In this study, simulated results during two periods representing the present (1980–2005) and future (2024–49) climates were analyzed.
- To investigate major TC activities over the WNP, the model output was converted to the analysis domain (0°–45 °N, 100°–160 °E) with 0.5° resolution.
- To diminish the uncertainty of a single RCM, the multi model ensemble (MME) mean of four RCMs was constructed using the performance-based ensemble averaging method proposed by Suh et al. (2012).

The CORDEX-East Asia domain with topography

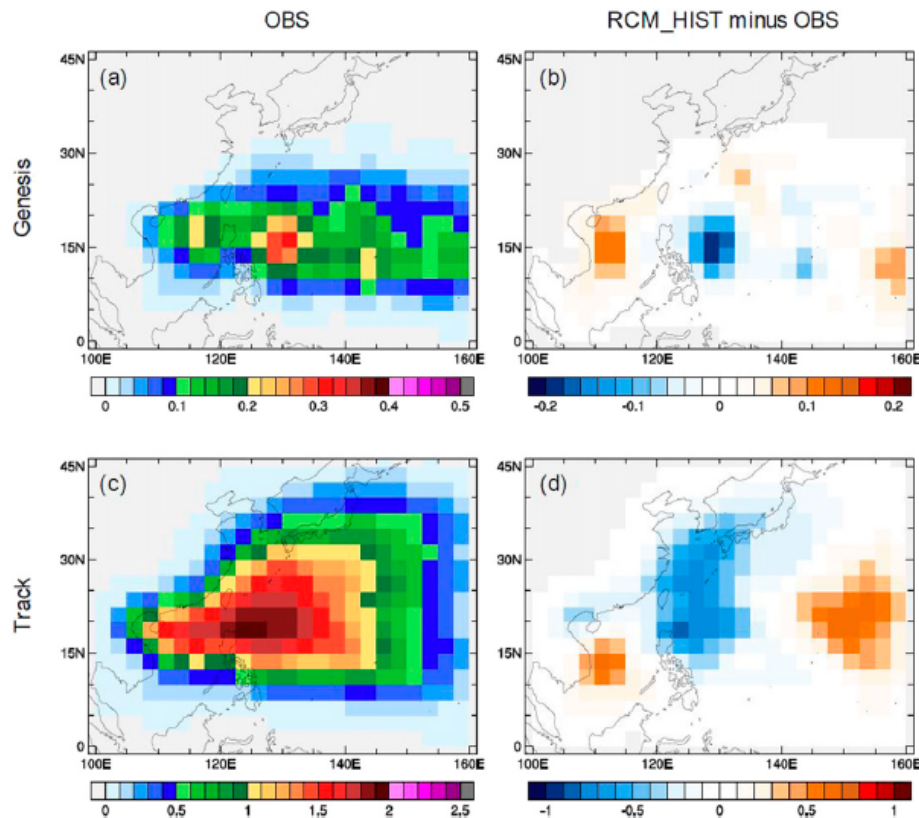


# Climatology of TC activity in the historical run

Climatology of TC activity in the historical run

## TC genesis and track

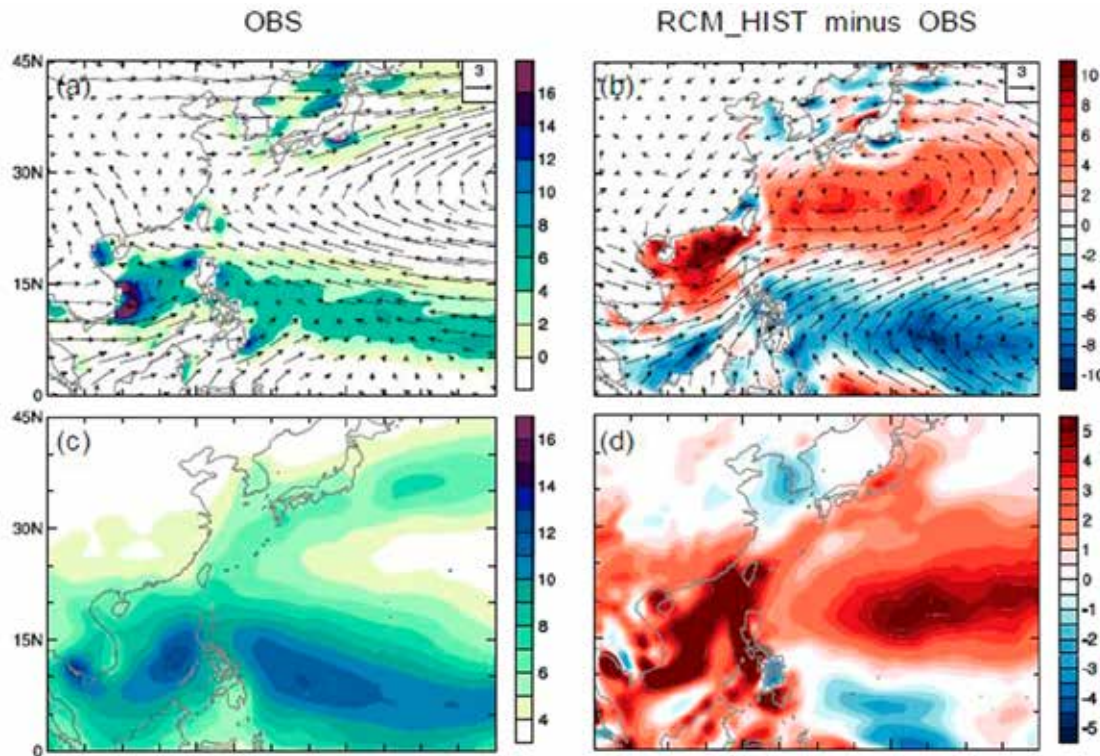
Climatological mean of TC (a), (b) genesis and (c), (d) track density in (left) observation and (right) differences between RCM\_HIST and observation for the period of 1980–2005.



- The locations of TC genesis in the observation are concentrated in the region between 5° and 25°N with three local maxima.
- Although positive (negative) bias of TC genesis is present in the east and west (vicinity) of the observed climatological mean genesis position (16.4°N, 136.1°E), the simulated genesis position (16.3°N, 135.6°E) roughly corresponds to the observation.
- The observed tracks are concentrated in the western part of the PS, whereas the simulated tracks are dispersed into the SCS and the eastern part of the WNP.

## Large-scale environments

Same as in previous figure, but for (a),(b) 850-hPa relative vorticity (shading) and 850-hPa wind (vectors), (c),(d) precipitation

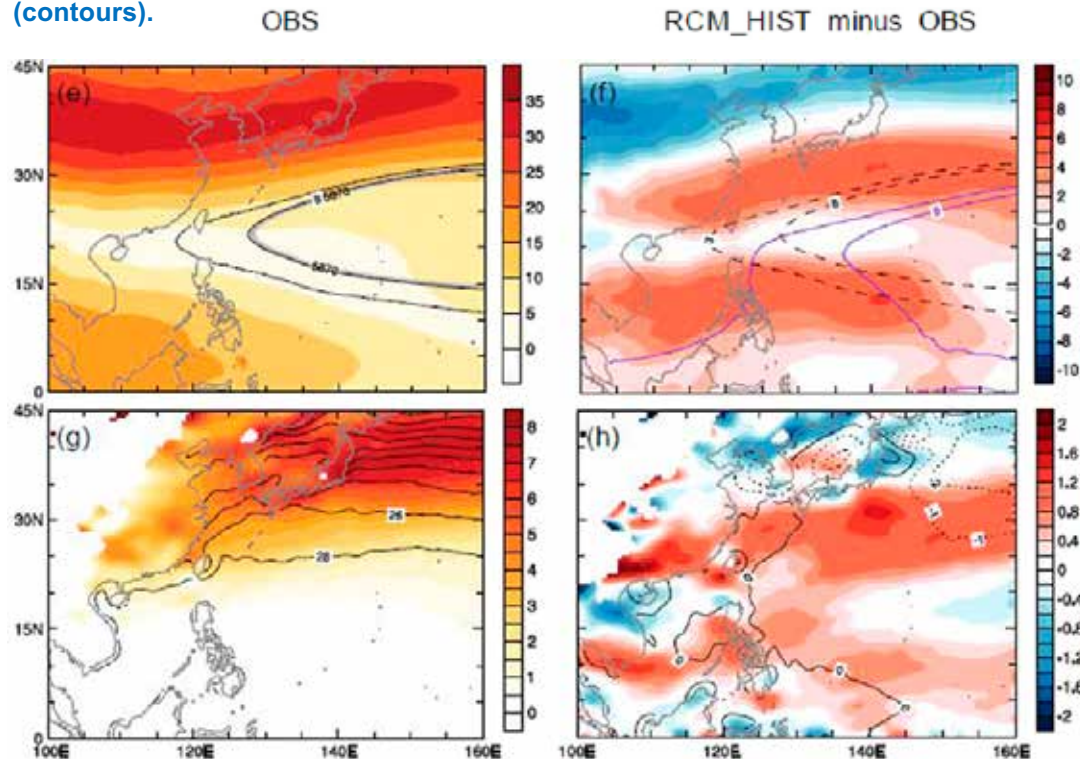


- In RCM\_HIST, the monsoon trough is stronger in the SCS, ECS, and southern coast of Japan but weaker in the tropical WNP compared to that in the observation.
- These positive and negative biases of relative vorticity could arise from enhanced lower-level southwesterly flow associated with excessively overestimated precipitation (i.e., convective activity) in the subtropical region and SCS (Figs. b,d).
- In the SCS, the strengthened monsoon trough and local convective activity appear to increase the frequency of TC formation.



## Large-scale environments

Same as in previous figure, but for (e),(f) vertical wind shear (shading) and 500-hPa eddy geopotential height (gpm), and (g),(h) meridional 850-hPa temperature gradient (shading) and sea surface temperature (contours).



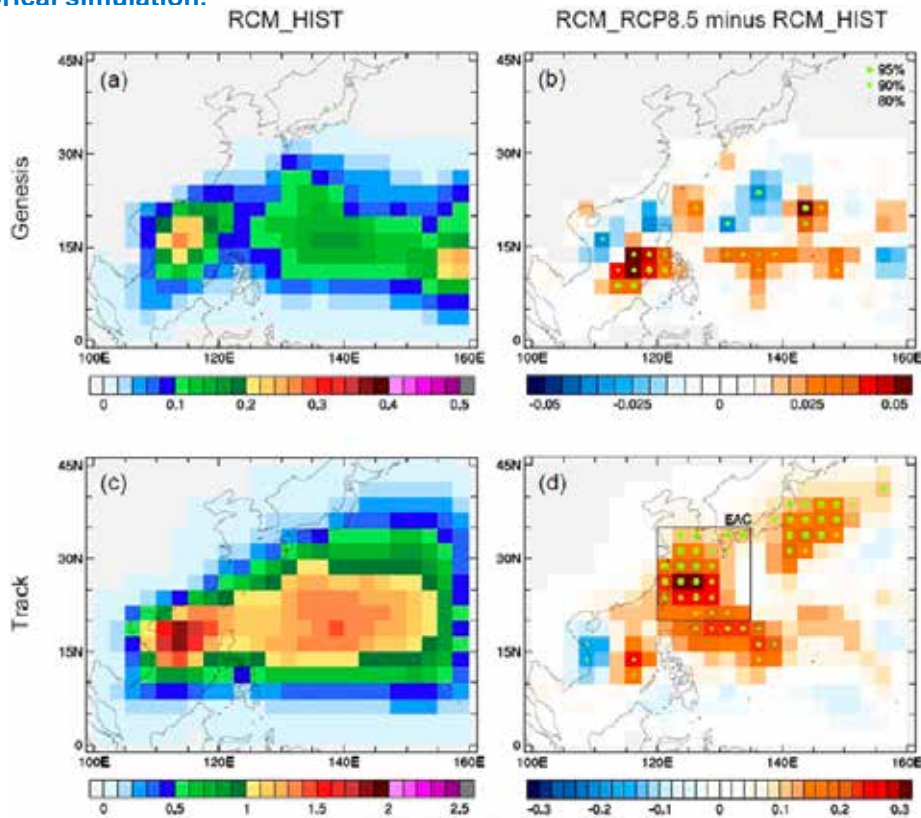
- In the RCM\_HIST, the VWS is overestimated below 30°N, and the WNPSH is shifted southeastward compared to observation.
- In the PS, the underestimated TC formation is associated with the weakened monsoon trough and shifted WNPSH (Fig. f).
- the meridional temperature gradient is overestimated at 30°N because of the differential warming between regions north and south of 30°N.

## Projected changes in TC activity

Projected changes in TC activity

# TC genesis and track

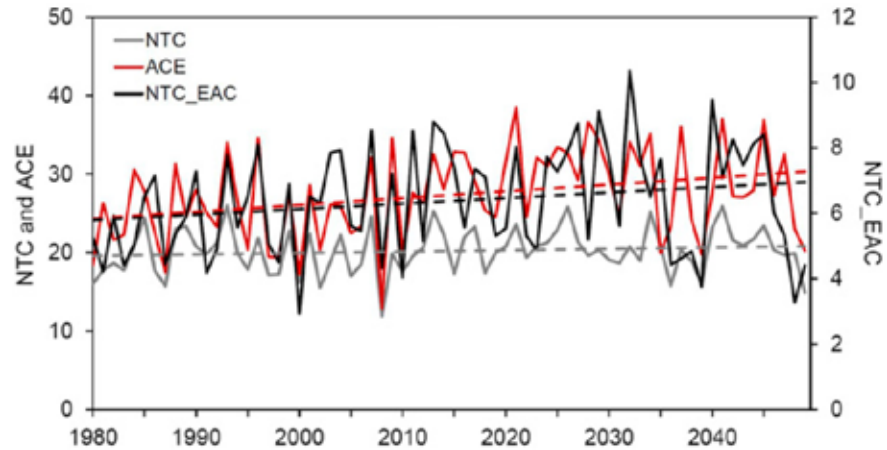
Climatological mean of TC (a), (b) genesis and (c), (d) track density in (left) historical simulation and (right) and (right) differences between the RCP8.5 future scenario (2024-49) and the historical simulation.



- The WNP TC genesis frequency is 20.7 in the RCM\_RCP8.5 run, which represents an insignificant increase of 5% compared to the frequency of 19.7 in the RCM\_HIST run.
- Overall, the future pattern of TC genesis tends to be shifted southeastward, far from the Asian continent.
- TC track density is increased robustly over the PS, ECS, and region southeast of Japan. Especially, the number of TCs entering the EAC (20°–35°N, 120°–135°E) is increased significantly (+17%).

# TC genesis and track

Annual number of TC geneses (solid gray), number of TCs entering the EAC region (solid black), and ACE (solid red). Dashed lines indicate the linear trends.

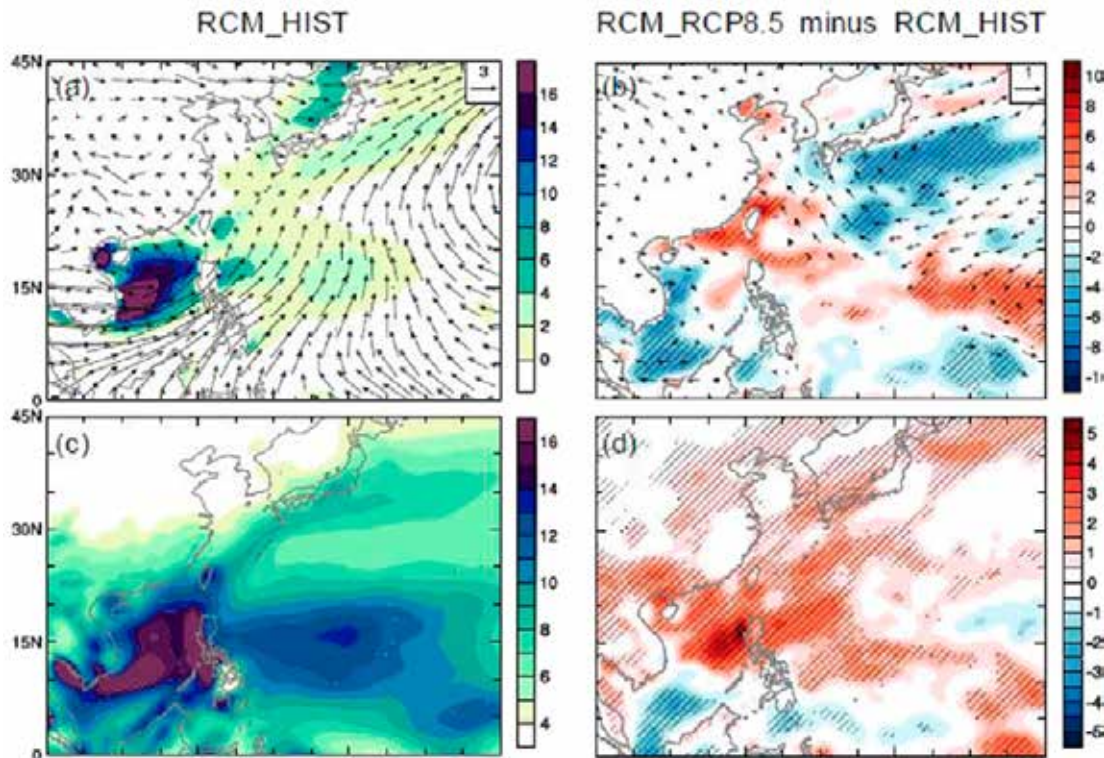


ACE, mean intensity, total number of TCs, and mean duration of TCs that are moving northward over 25°N.

	RCM_HIST	RCM_RCP8.5	Change
ACE	4.4	6.5	2.0 (+45.9%)
Mean Intensity	22.7	23.8	1.1 (+4.8%)
NTC	8.7	9.4	0.7 (+8.0%)
Mean duration	2.22	2.65	0.44 (+19.7%)

## Large-scale environments

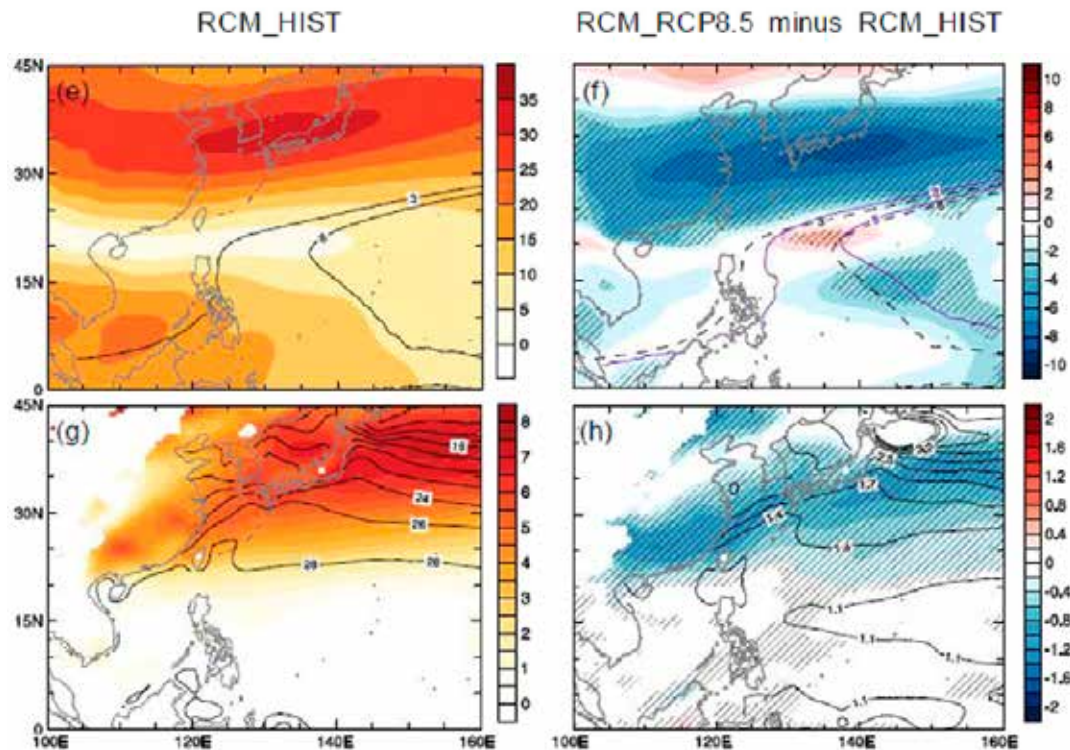
(a),(b) 850-hPa relative vorticity (shading) and 850-hPa wind (vectors),  
(c),(d) precipitation



- To understand the possible causes for the future changes in TC track and genesis, we examined projected changes in large-scale environments induced by climate change
- In RCM\_RCP8.5, slightly increasing TC genesis frequencies over the tropical WNP and Mariana Trench are associated with a slightly enhanced monsoon trough and weakened VWS.

## Large-scale environments

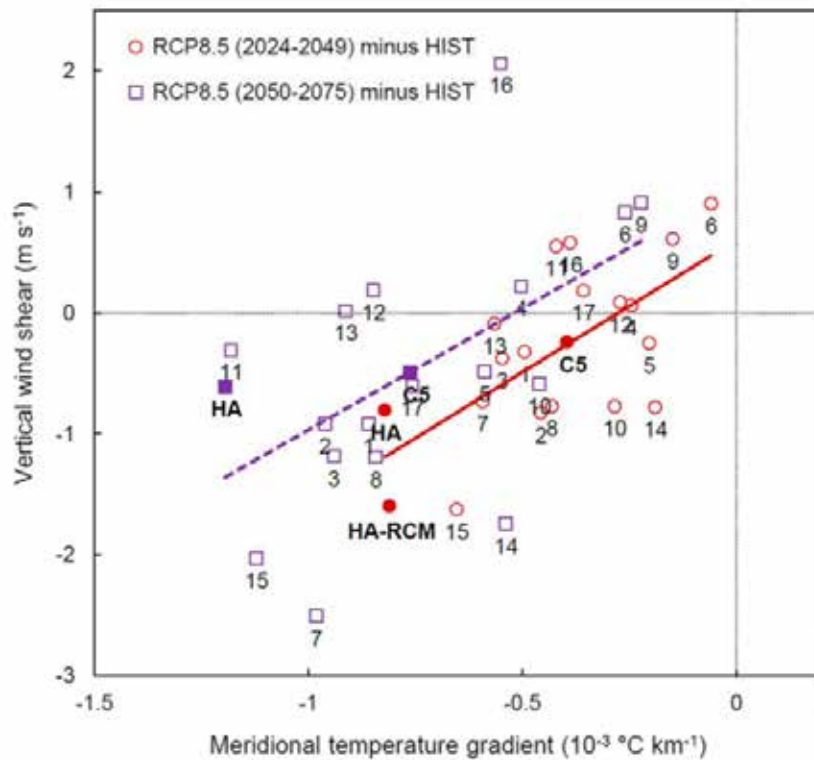
(e),(f) vertical wind shear (shading) and 500-hPa eddy geopotential height (gpm), and (g),(h) meridional 850-hPa temperature gradient (shading) and sea surface temperature (contours).



- Compared to the tropical region, mid-latitude SST warming is larger, with maximum warming at 40°N.
- This differential warming indicates that the meridional temperature gradient decreases around 30°N
- In turn, the decreasing meridional temperature gradient would result in significantly reduced VWS (i.e., upper-level westerly flow) in the mid-latitudes and could provide a favorable condition for TC passage through the reduced VWS region near the EAC and southeast of Japan

# Large-scale environments

Scatter diagram for the changes in vertical wind shear as a function of meridional temperature gradient averaged over 25–40N, 120–145E under RCP8.5 for the periods of 2024–49 (red circles) and 2050–75 (purple squares) compared to the historical run (1980–2005).

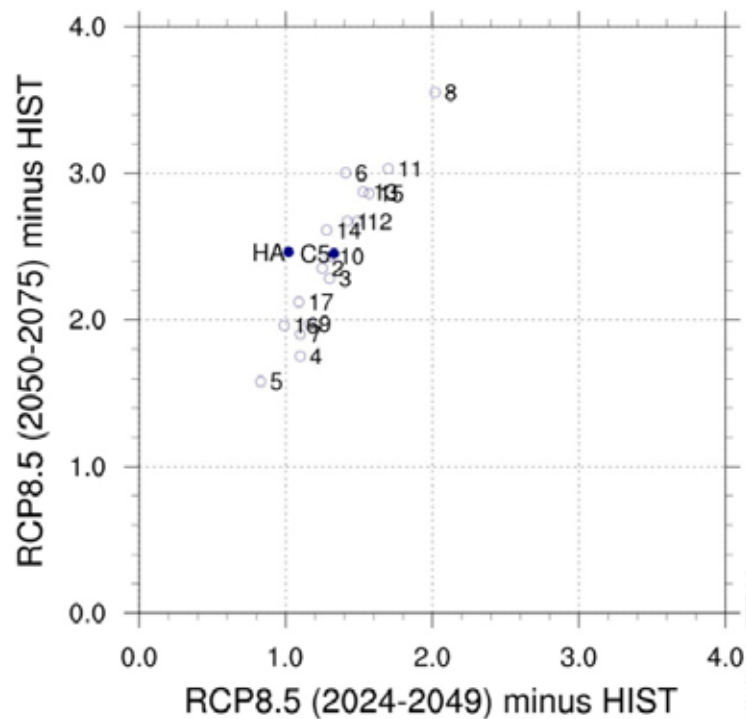


The 17 CMIP5 models used to calculate VWS and meridional temperature gradient.

Model name	No.
ACCESS1-0	1
BNU-ESM	2
CanESM2	3
CESM1-BGC	4
CNRM-CM5	5
CSIRO-Mk3-6-0	6
FGOALS-g2	7
GFDL-CM3	8
GFDL-ESM2M	9
GISS-E2-R	10
HadGEM2-CC	11
HadGEM2-ES	12
IPSL-CM5A-LR	13
MIROC5	14
MIROC-ESM	15
MPI-ESM-LR	16
NorESM1-M	17

## Large-scale environments

Scatter diagram for the sea surface temperature change over 25–40N, 120–145E under RCP8.5 for the periods of 2024–49 and 2050–75 compared to the historical run (1980–2005).



- All CMIP5 models simulate warmer SST than the historical run and an increasing trend of SST in the far future (2050–75) that is larger than that in the near future (2024–49).
- This provides confidence that future changes in SST can increase TC activity in the mid-latitudes.
- Finally, weakened VWS as well as increased SST over the mid-latitudes leads to increasing lifetime of TCs.



## Conclusions and discussion

- **Simulation of the present (1980–2005; historical) and projected (2026–49; RCP8.5) WNP TC activity was conducted using four 50-km RCMs.**
- **The simulated climatological mean TC activity for the present climate shows many characteristics similar to observations, such as the seasonal features of TC genesis and tracks.**
- **The enhanced TC activity over EAC regions is mainly related to vertical wind shear weakened by reduced meridional temperature gradient and increased SST at mid-latitudes.**
- **VWS as a function of the meridional temperature gradient of HadGEM2-AO was compared with the 17 CMIP5 model ensemble. VWS and meridional temperature gradient show a positive correlation between them and a decreasing trend in future climate. Also, a consistent increasing signal is revealed for SST.**



**THANK YOU**

**FIRST IN CHANGE**

## Supplementary material

### Tracking method

- The detection and tracking methods of TCs method employed in this study were almost similar to that in Jin et al. (2015), except for some thresholds.
- 1. Local minimum position of sea level pressure was the potential TC core
- 2. The maximum wind at the surface was stronger than the wind speed threshold
- 3. The maximum wind speed at 850 hPa was larger than that at 300 hPa
- 4. The temperature deviations from the environment at three levels (200, 500, and 850 hPa) was larger than the threshold of temperature anomaly
- 5. The maximum value of 850-hPa relative vorticity exceeded the threshold of vorticity
- 6. The lifetime should be longer than 2 days
- 7. Tracks were traced from the identified potential TCs

## Supplementary material

### Thermal wind relationship (temperature -> zonal wind)

Two basic assumption

1. Hydrostatic equation ( balance between gravity F & vertical pressure gradient F)

$$\frac{\partial \phi}{\partial p} = -\alpha = -\frac{RT}{P}$$

2. Geostrophic balance (balance bet. horizontal pressure gradient F~ Coriolis F)

$$fu = -\frac{\partial \phi}{\partial y}$$

Combine two equations

$$\frac{\partial u}{\partial p} = \frac{R}{fP} \left( \frac{\partial T}{\partial y} \right)$$

we can derive the vertical distribution of zonal wind (u), solely determined by meridional temperature gradient

## Supplementary material

Thresholds used for the relative vorticity, surface wind speed, and warm-core temperature for defining TCs in the WNP.

	RegCM	SNURCM	WRF	GRIMs
Vorticity ( $10^{-5} \text{ s}^{-1}$ )	7.7	8.0	8.2	8.9
Temperature (K)	1.3	1.5	1.0	1.6
Wind speed ( $\text{m s}^{-1}$ )	16.1	17.0	15.5	16.8