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Tropical Cyclone Genesis and Favorable Environmental Conditions in the Western North Pacific

Xiong Rui & Lu Mengqian

Supervisor: Prof. Lu Mengqian

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Motivation

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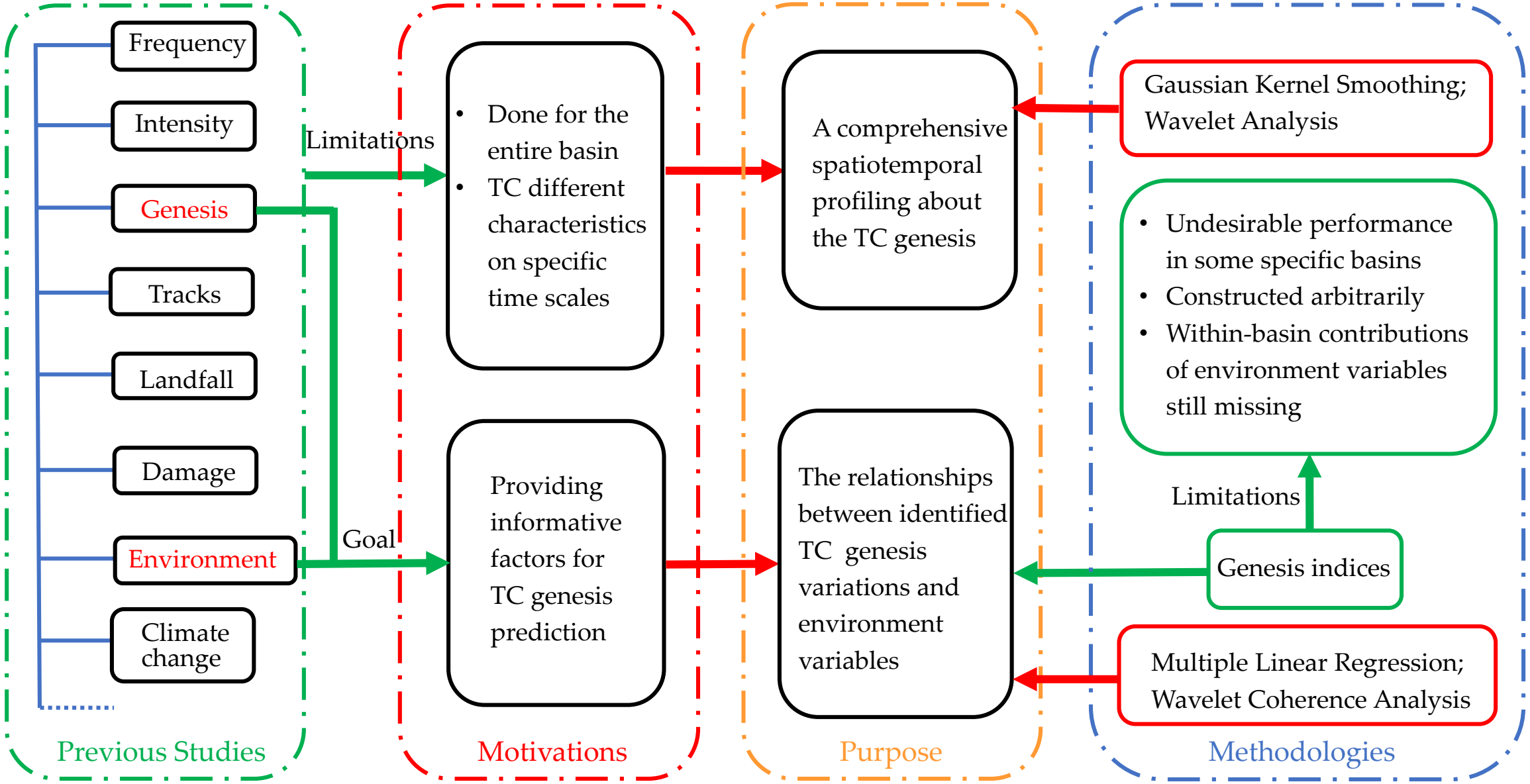
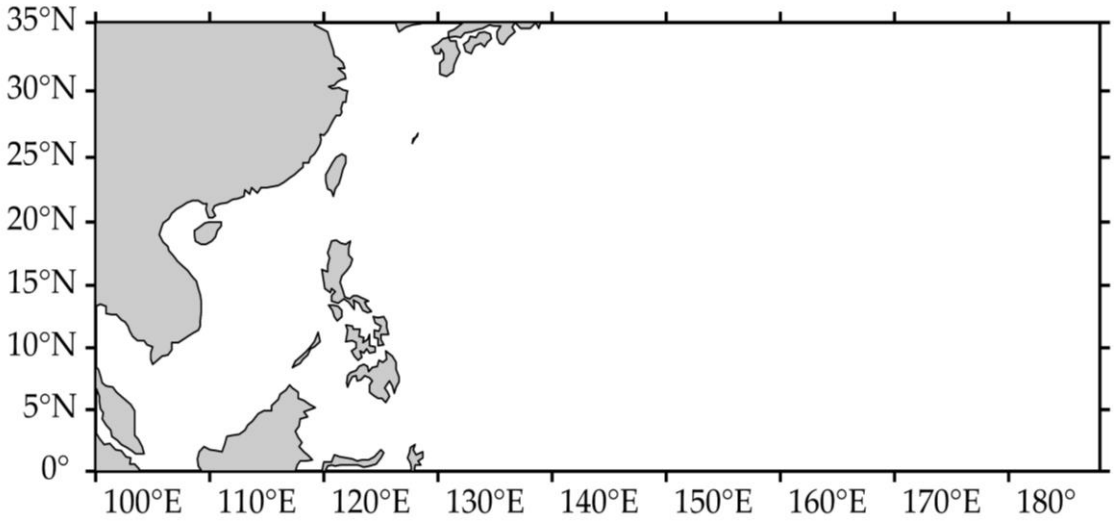


Data



Study area: WNP (0° – 35°N, 100° – 188°E)

Study period: 1979 – 2017

TC origins data (JMA)

Monthly Oceanic Niño Index (NOAA)

Environmental variables (ERA5)

- vertical shear of zonal wind (V_{zs}): 200mb – 850mb
- relative humidity (RH): 600mb
- absolute vorticity (Vor): 850mb

(Spatial resolution: 1° × 1°, Temporal resolution: Daily)

(Gray, 1975; Wang & Moon, 2017a; Wei et al., 2018)

Methodology

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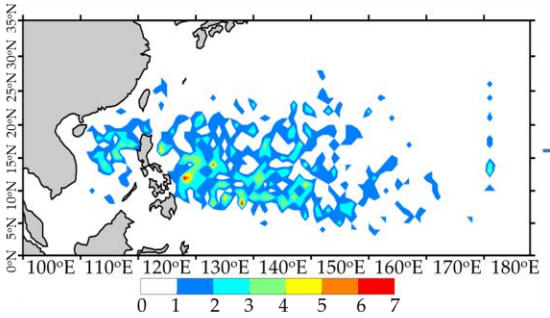
Discrete, space-time process

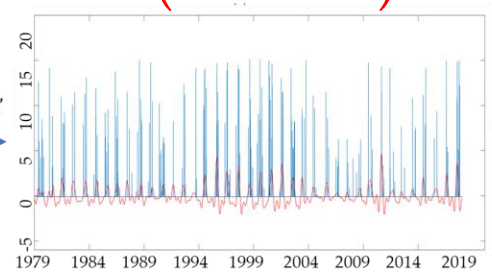


GKS normalization

$$K_L(d_L,h)=\frac{1}{\sqrt{2\pi h}}e^{-d_L^2/2h^2},\quad Y^*_{L,d^j}=\frac{\hat{Y}_{L,d^j}}{\sum_{l=L(36,89)}^{l=L(1,1)}\sum_{d^j=1}^{n^j}\hat{Y}_{l,d^j}}$$

$$\hat{Y}_{L,t}=\sum_{i=1}^{N_t}K_L(d_i^t,h)\times Z_i^t,$$

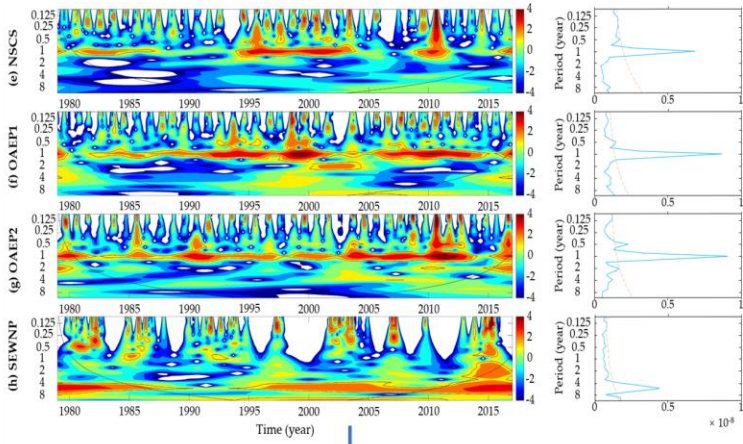
Spatially averaged TC rate (blue line)



Wavelet analysis

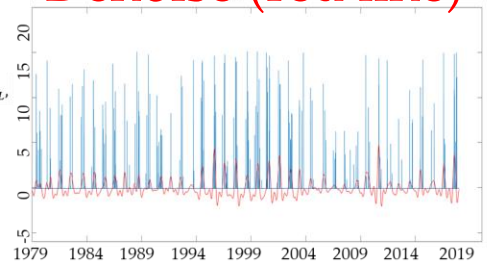
$$\psi(\eta)=\pi^{-1/4}e^{i\omega\eta}e^{-\eta^2/2},$$

Complete time-frequency space



Reconstruction on substantial frequency bands

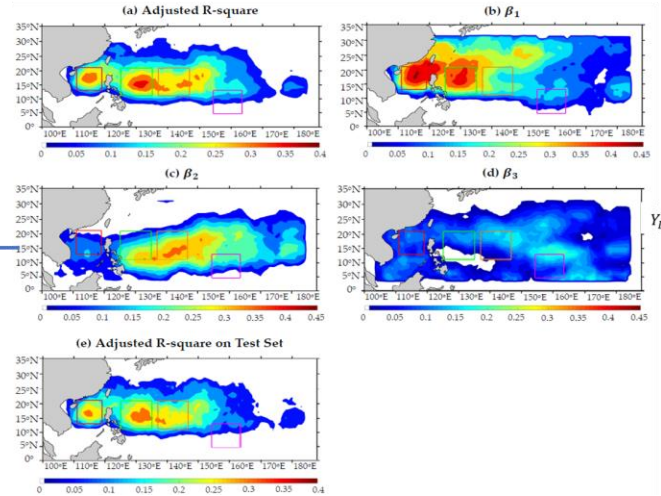
Denoise (red line)



Linear regression

$$Y_L^{Re}=\beta_{L,1}V_{zs_L}+\beta_{L,2}RH_L+\beta_{L,3}Vor_L+\varepsilon_L,$$

Linear relationships

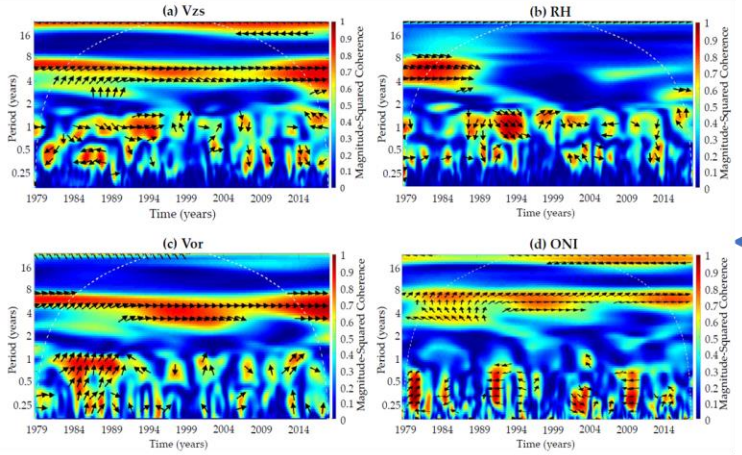


Wavelet coherence analysis

$$WC(s)=\frac{|W_n^{XY}(s)|^2}{W_n^X(s)\cdot W_n^Y(s)},$$

$$\theta=\arg(WCS)\ \ with\ WCS=\frac{W_n^{XY}(s)}{\sqrt{W_n^X(s)}\cdot\sqrt{W_n^Y(s)}},$$

Non-linear relationships



Results – *Genesis spatiotemporal variations*

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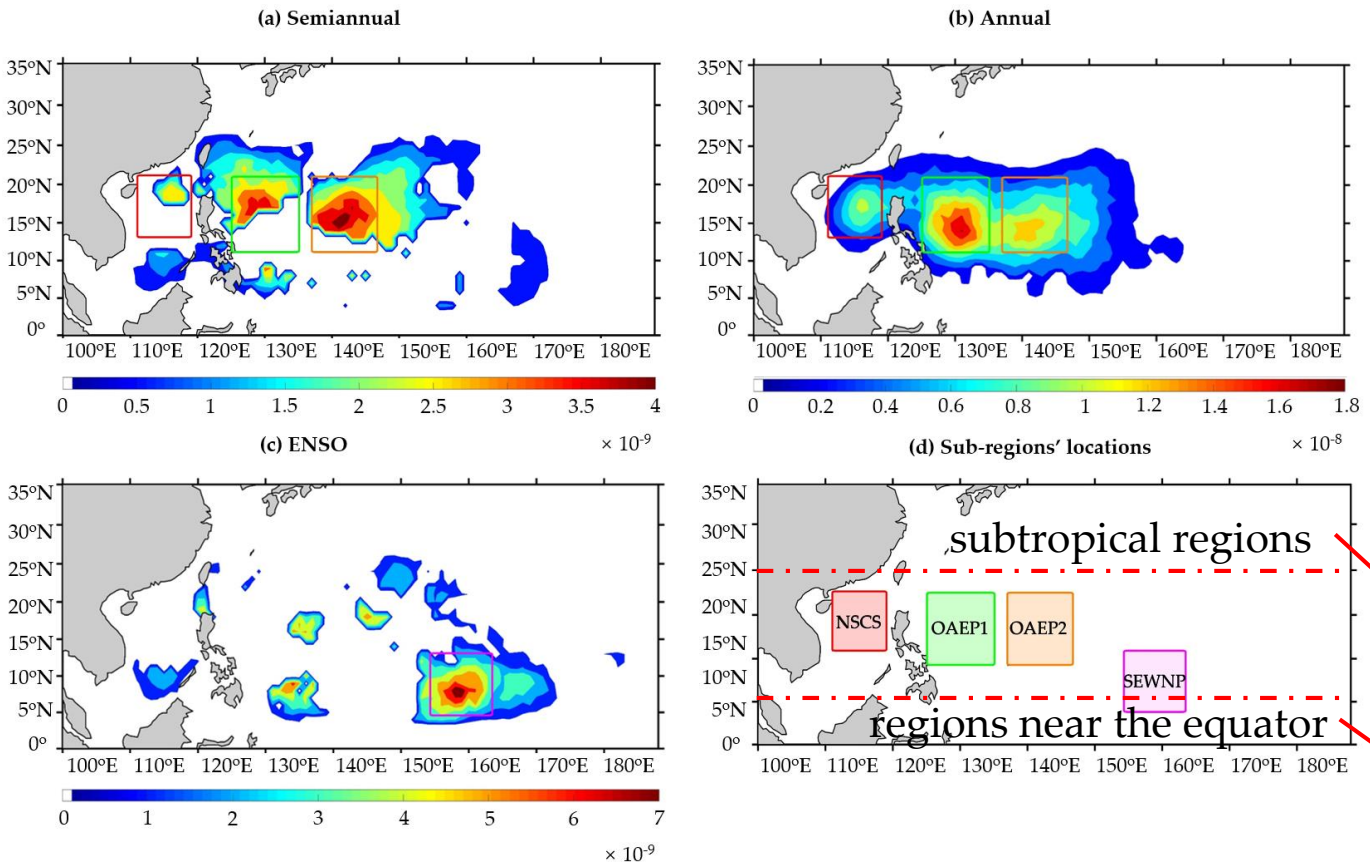

Figure 1. Spatial distributions of significant TC variations on (a) semiannual (b) annual (c) ENSO timescales

NSCS: northern South China Sea;

OAEP: oceanic areas east of the Philippines;

SEWNP: southeastern part of western north Pacific.

NSCS, OAEP: Semiannual and annual time scales

Possible mechanisms:

For NSCS and OAEP,

- more favorable environmental variables, e.g.

a. smaller vertical shear of zonal wind, higher SST;

(Gray & Brody, 1967; Yuan et al., 2007)

b. higher Coriolis force;

(Gray, 1979; Wang et al., 2007)

Results – *Genesis spatiotemporal variations*

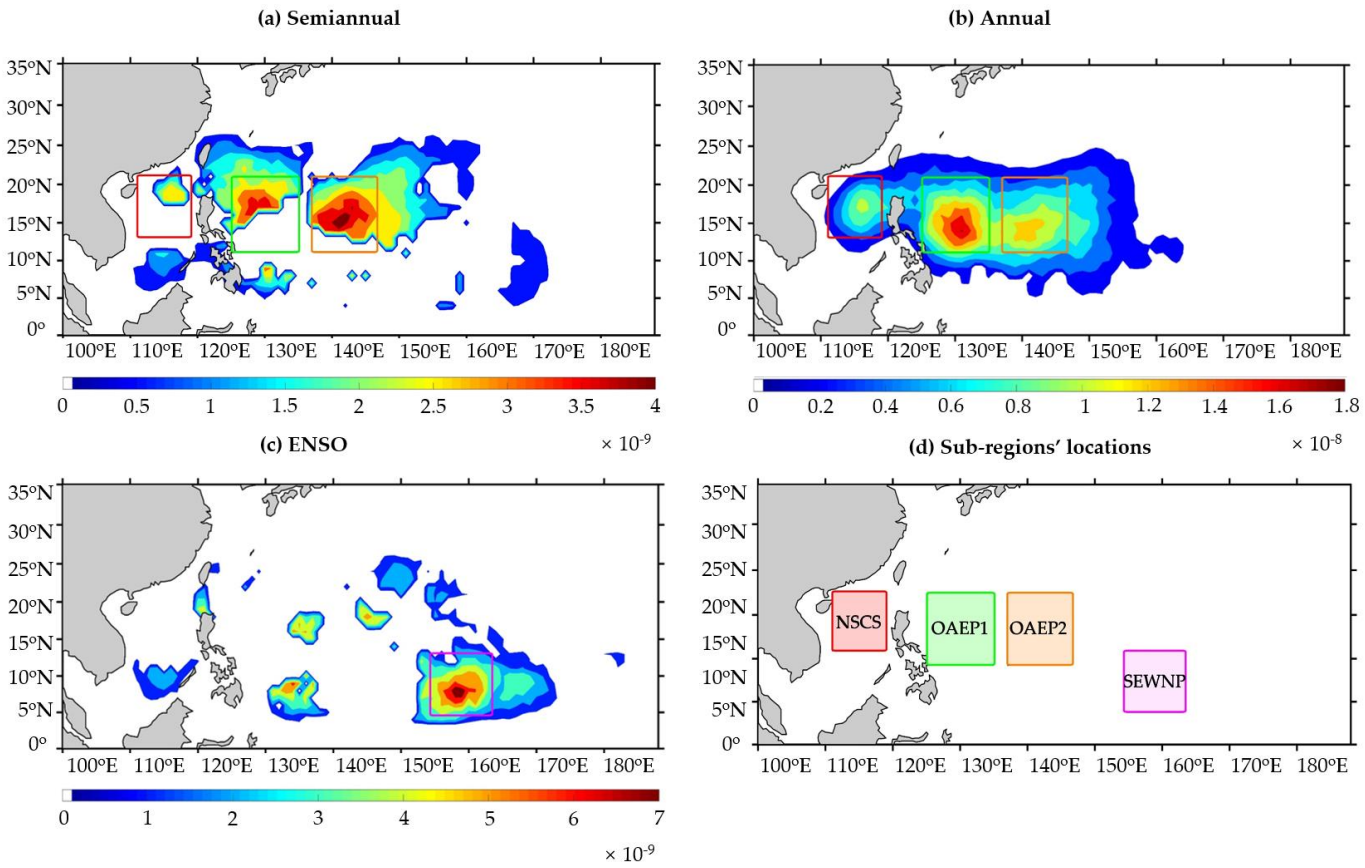

Figure 1. Spatial distributions of significant TC variations on (a) semiannual (b) annual (c) ENSO timescales

SEWNP: ENSO time scale

Possible mechanisms:

For SEWNP,

- A southeast-northwest oscillation of TC genesis induced by
  a. east-west Walker Circulation variation (warmer and higher RH air);
  (Chan, 1985)
  b. eastward extension – westward retraction of the monsoon trough (greater vorticity);
  (Du et al., 2011; Wang & Chan, 2002)
  c. intertropical convergence zone (ITCZ)
  (Wang & Magnusdottir, 2006)

Results – *Genesis spatiotemporal variations*

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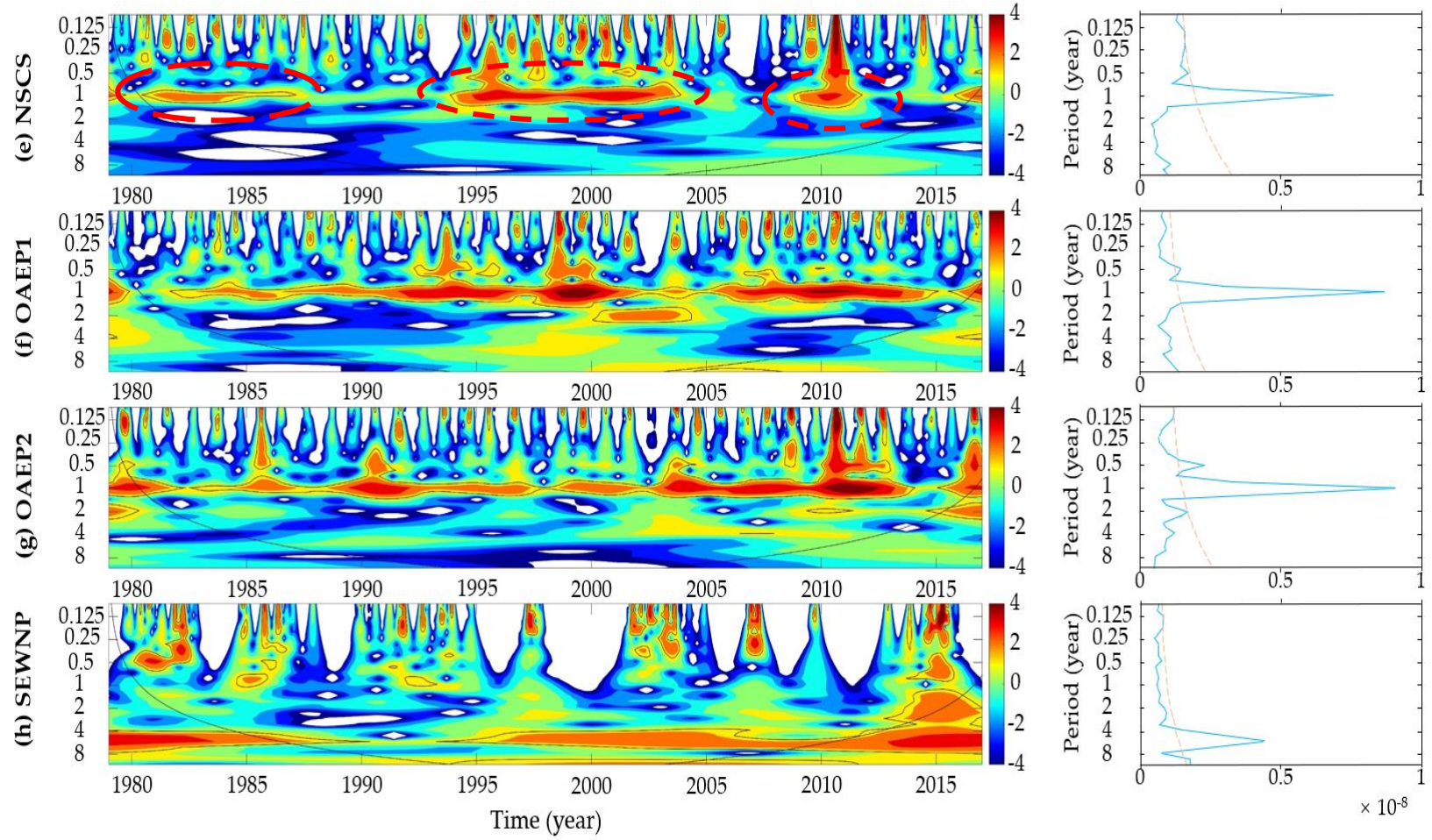

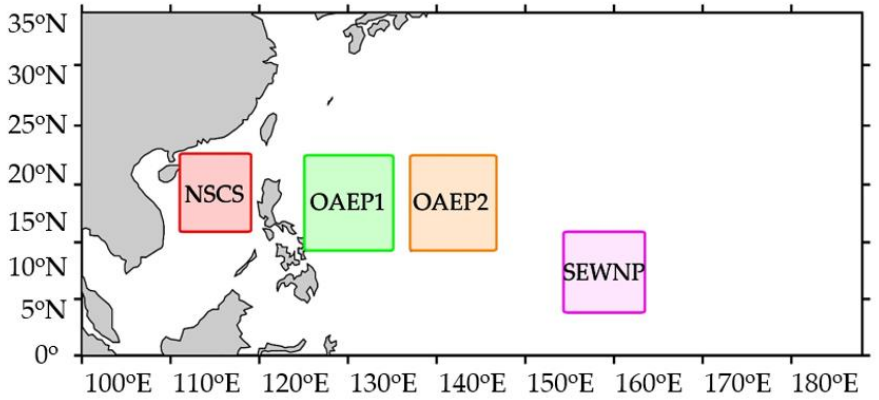

Three active TC periods in NSCS

(1981–1987, 1994–2004, and 2009–2011)

Possible mechanisms:

- The El Niño Modoki and the canonical El Niño (Chen, 2011);
- The Phase of Indian ocean SST (Wang et al, 2013)

Figure 2. Time-frequency profiles for (e) NSCS (f) OAEP1 (g) OAEP2 (h) SEWNP. The color bar shows the unitless spectra power; the right columns are the global wavelet spectra averaged over 39 years.

Results – *Genesis spatiotemporal variations*

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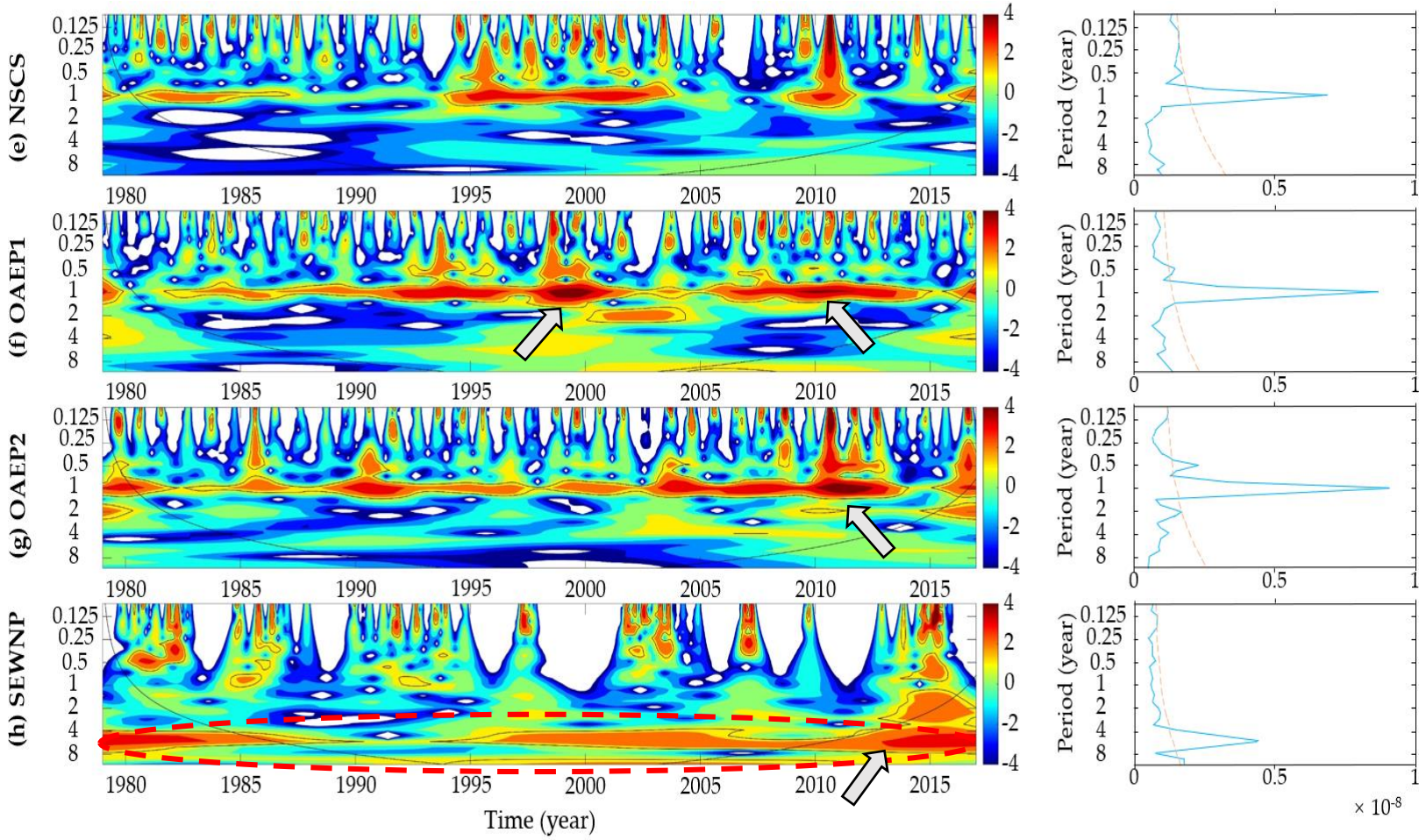

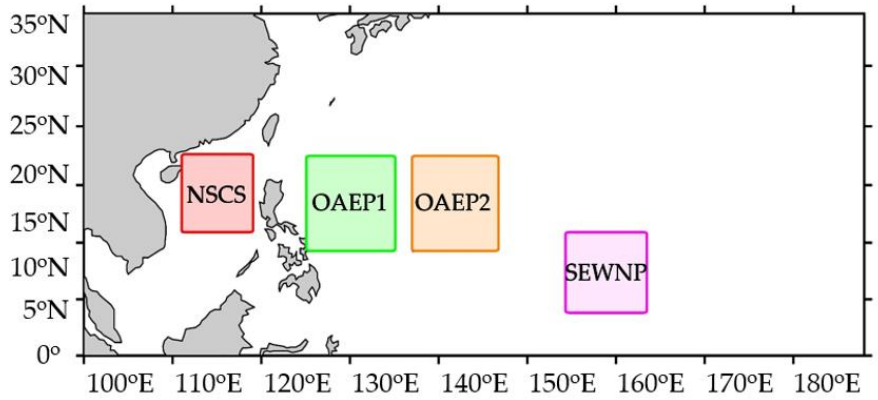

Some notable intensification around 1999 and 2011 in OAEP

Possible mechanisms:

- strong La Niña years (1999, 2011)

Variations on ENSO time scale are substantial overall

Figure 2. Time-frequency profiles for (e) NSCS (f) OAEP1 (g) OAEP2 (h) SEWNP. The color bar shows the unitless spectra power; the right columns are the global wavelet spectra averaged over 39 years.

Results – *Linear Relationships*

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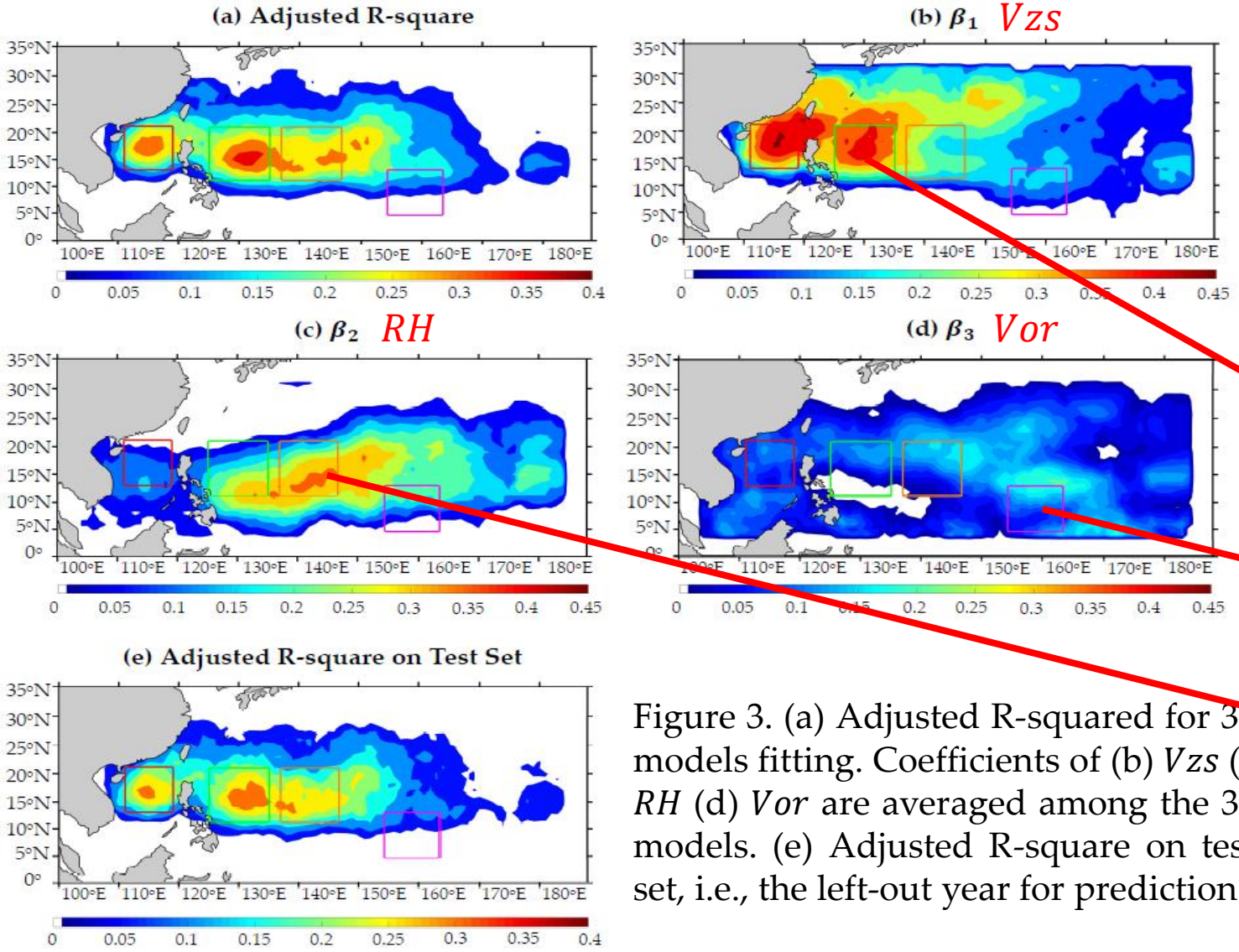
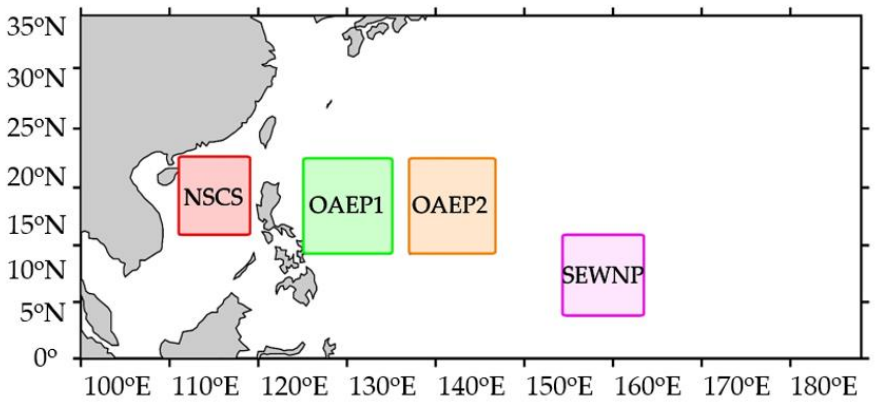


Figure 3. (a) Adjusted R-squared for 39 models fitting. Coefficients of (b) Vzs (c) RH (d) Vor are averaged among the 39 models. (e) Adjusted R-square on test set, i.e., the left-out year for prediction.



- Large V_{zs} variability
- Key role: Low-level vorticity
- Easterly trade winds (Walker Circulation)

Results – *Linear Relationships*

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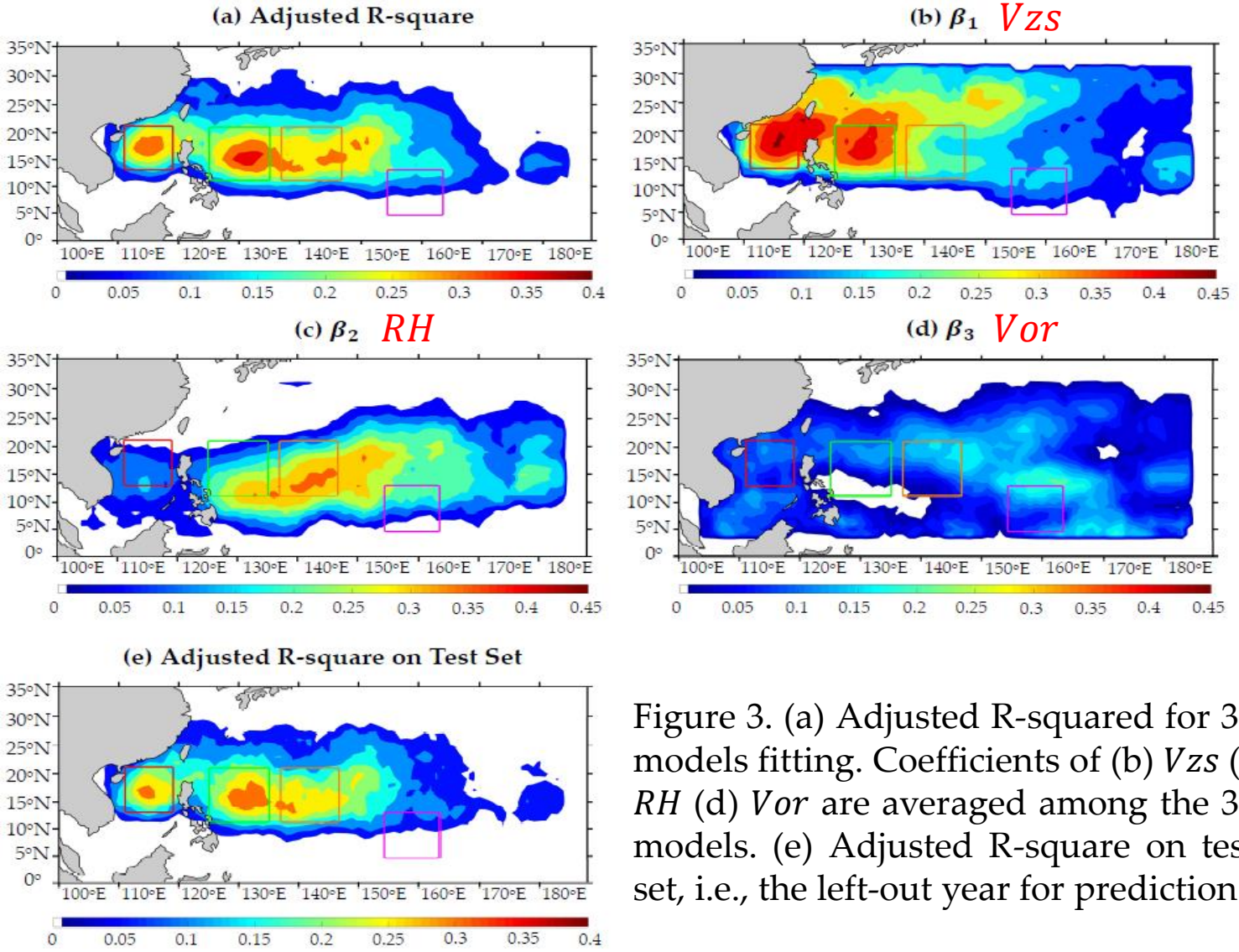

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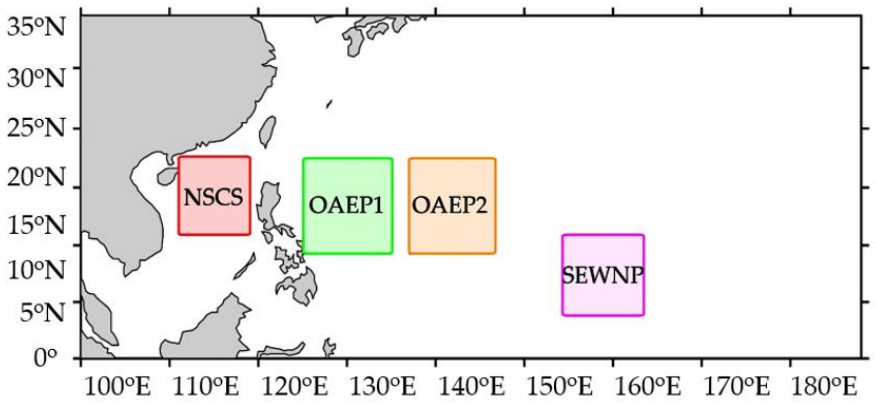

NSCS, OAEP: V_{zs} and RH
SEWNP: V_{zs} and Vor

Importance: $V_{zs} \approx 2RH/Vor$

Results – *Nonlinear Relationships*

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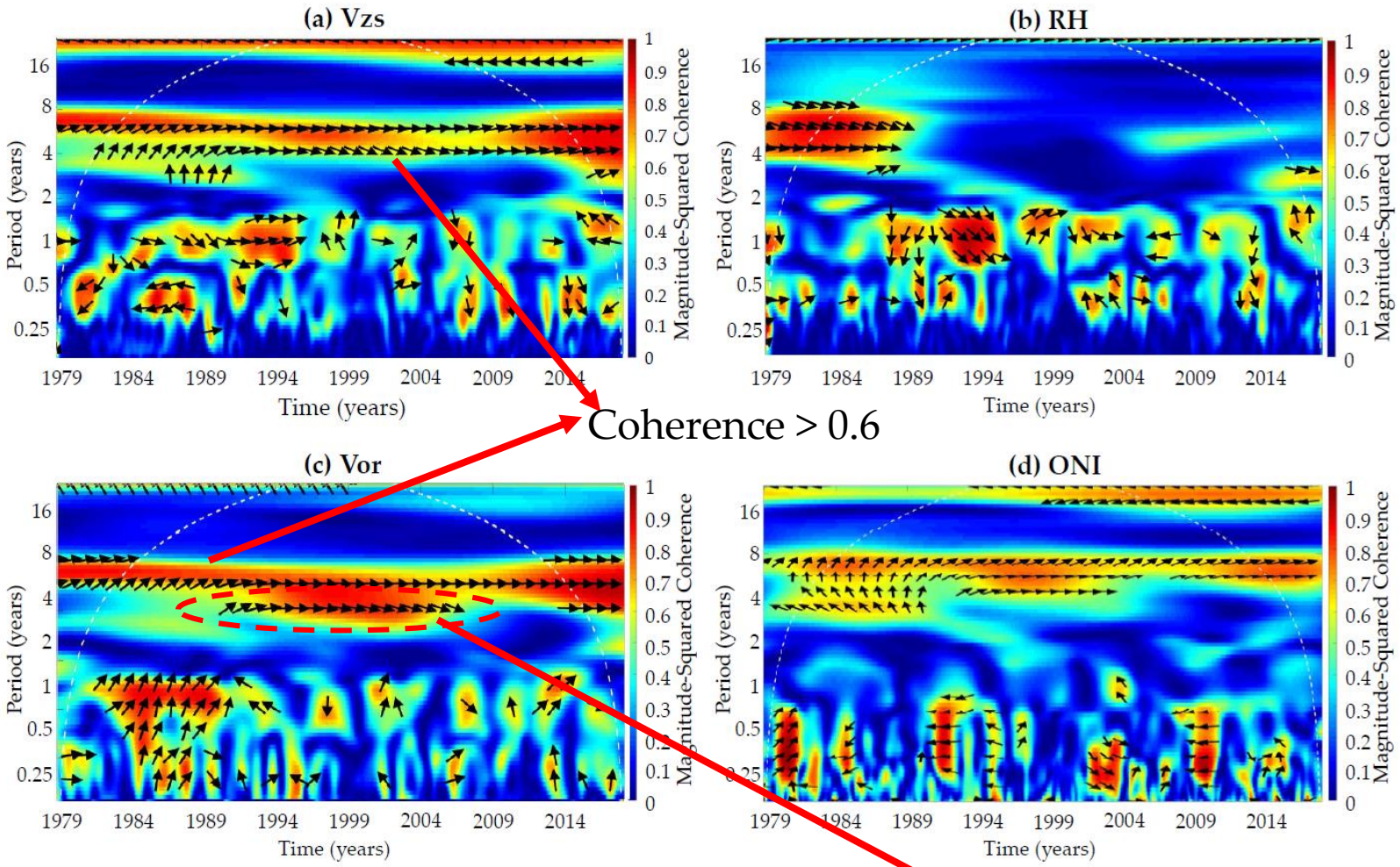

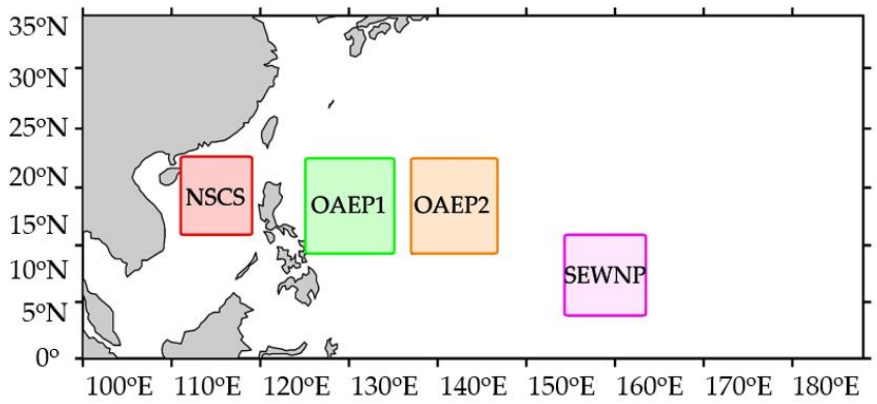

- Significant coherence on the 4- to 8-year frequency band (ENSO timescale)
- Consistent in-phase relationships

Local responses to ENSO signals

Figure 4. Wavelet coherence and phase relationships between reconstructed TC and (a) *Vzs*, (b) *RH*, (c) *Vor* and (d) ONI in SEWNP.

A shorter response time (1989 to 2004)

Results – *Nonlinear Relationships*

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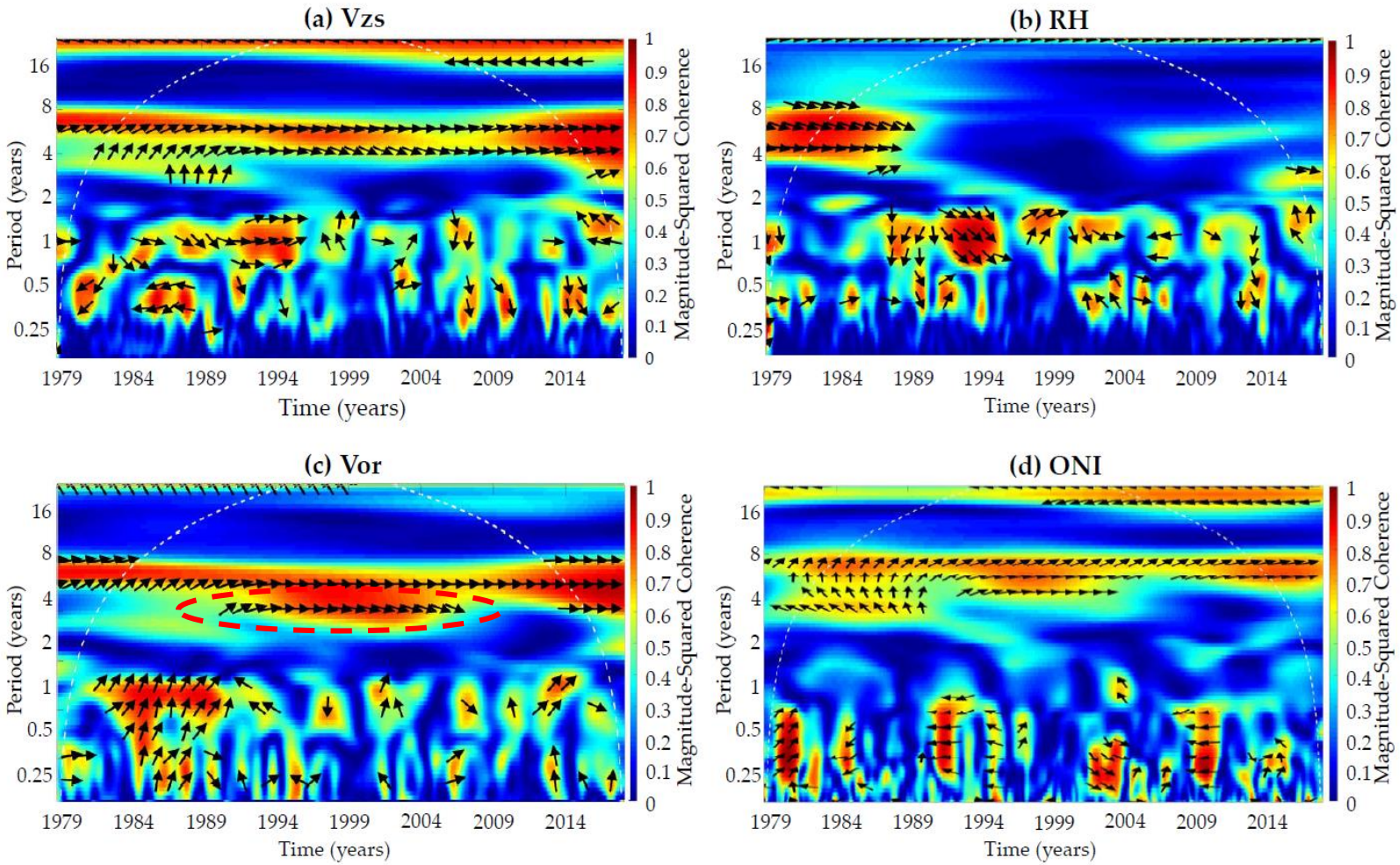

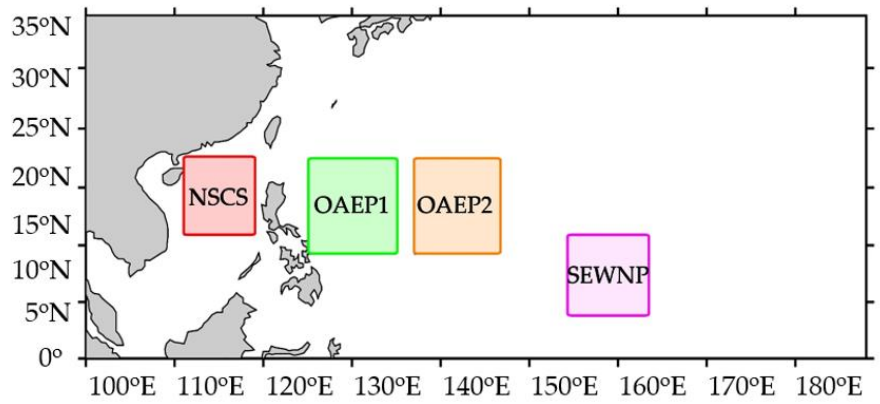

V_{zs} and Vor: high coherence and in-phase relationships

NSCS, OAEP: V_{zs} and RH
SEWNP: V_{zs} and Vor

Figure 4. Wavelet coherence and phase relationships between reconstructed TC and (a) Vzs, (b) RH, (c) Vor and (d) ONI in SEWNP.

Results – *Nonlinear Relationships*

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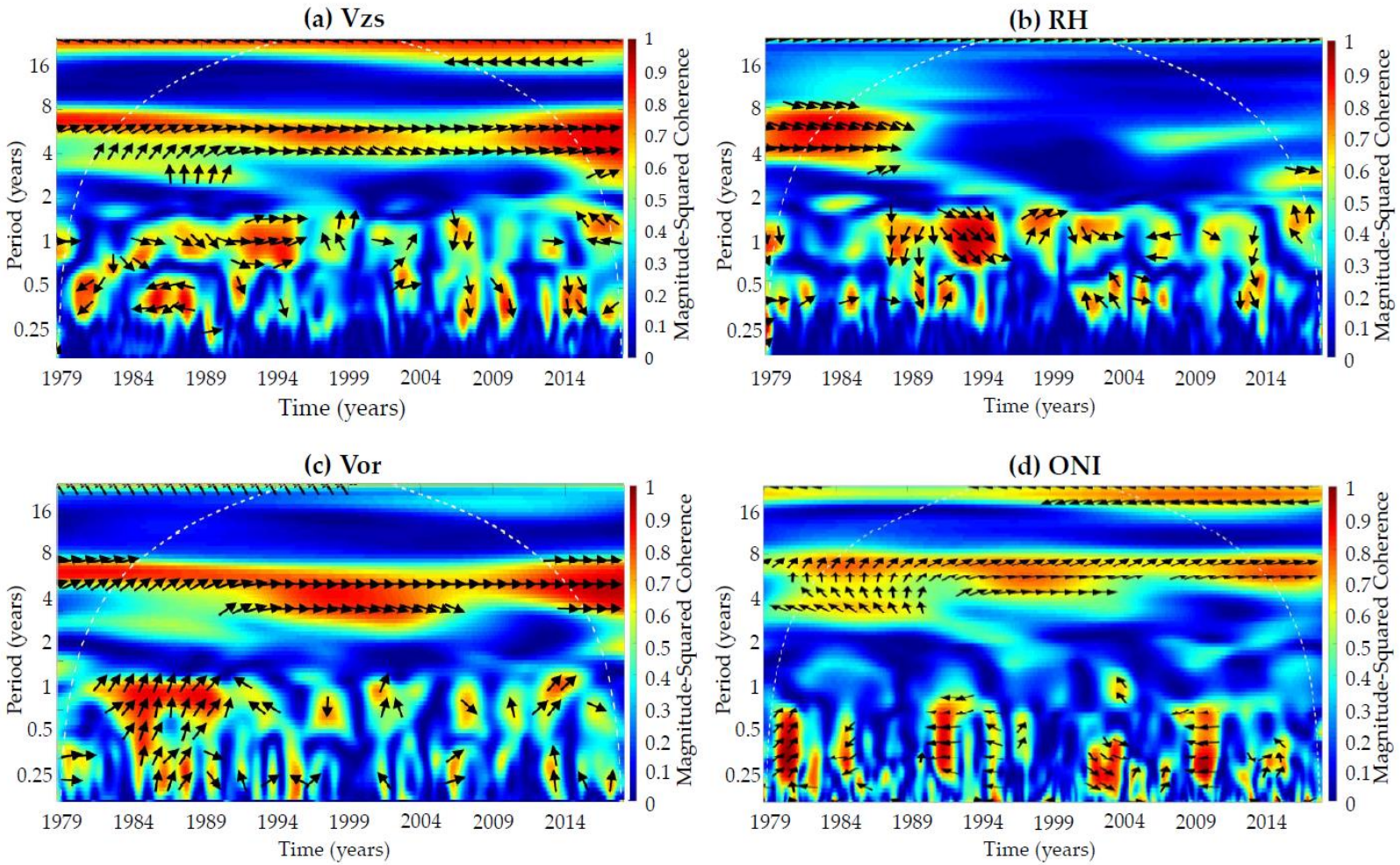

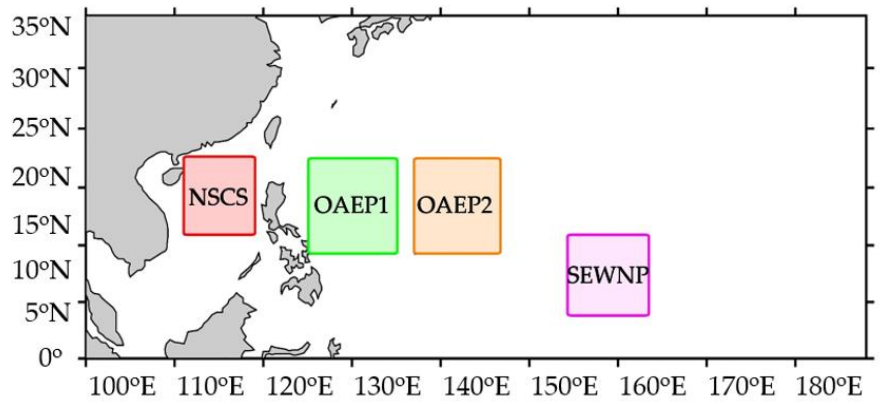

TC and ONI:

weak Pearson correlation coefficient (< 0.1), but significant wavelet coherence (overall > 0.7)

TC variations and ENSO: strong nonlinear and nonstationary relationships

Figure 4. Wavelet coherence and phase relationships between reconstructed TC and (a) *Vzs*, (b) *RH*, (c) *Vor* and (d) ONI in SEWNP.

Conclusions

- There are significant semiannual and annual variations of TC genesis over the northern South China Sea and oceanic areas east of the Philippines.
- Variations on the El Niño–Southern Oscillation timescale are prominent between 5–10°N, 155–160°E.
- Over northern South China Sea and oceanic areas east of the Philippines, 40% of the reconstructed TC variance can be explained by vertical shear of zonal wind, relative humidity, and absolute vorticity.
- The reconstructed TC series near (160°E, 7°N) has strong but varying in-phase relationships with El Niño–Southern Oscillation.