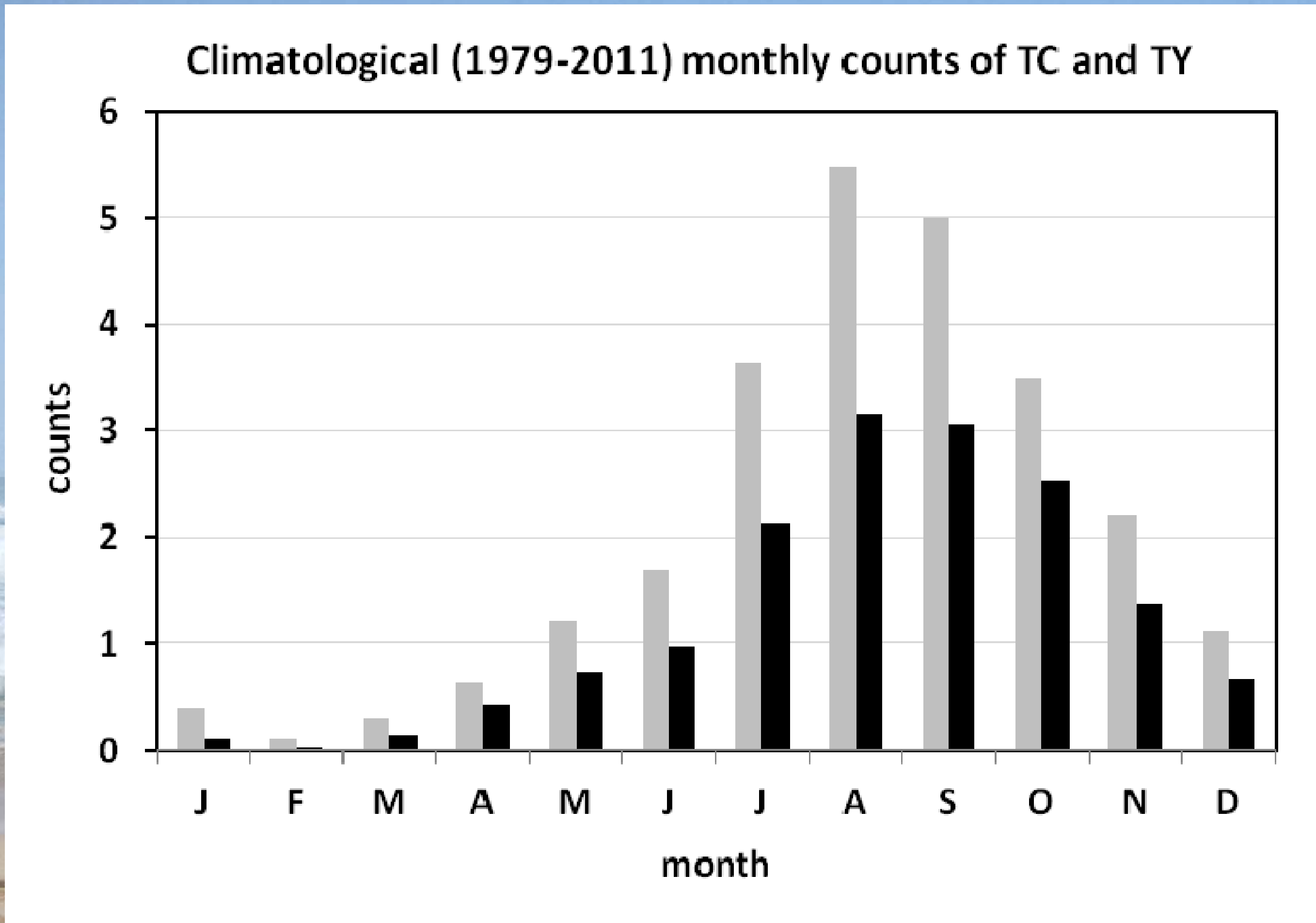
Has the Late-season Typhoon Activity over the Western North Pacific changed since 1979?

Pang-Chi Hsu, **Pao-Shin Chu**, Hiroyuki Murakami, and Xin Zhao

University of Hawaii

Central Weather Bureau conference 2014

Journal of Climate, 2014, 4296-4312



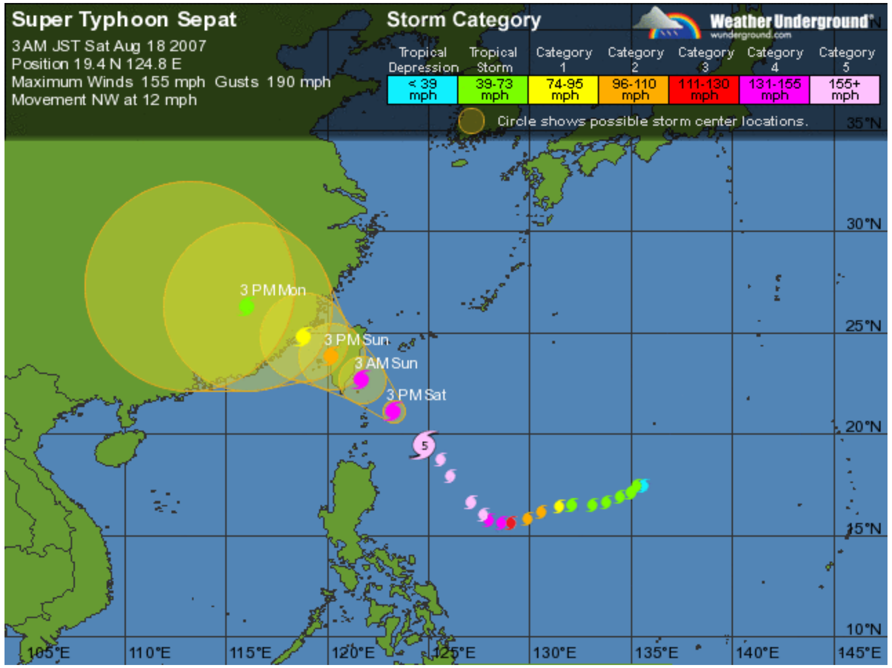
Late season: OND
Peak season: JAS

Grey: tropical storm
Black: typhoon
Data source: RSMC-Tokyo
68% TS grows to typhoons in OND vs 59% during the peak season

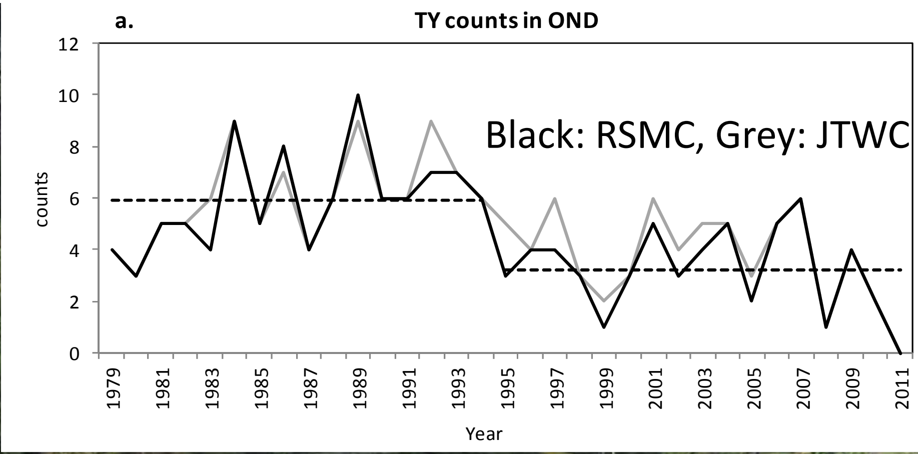
Supertyphoon Megi in Oct 2010, Cat-5 supertyphoon Bopha in Nov 2012, and cat-6 supertyphoon Haiyan in Nov 2013

- Typhoons are defined as tropical cyclones that possess 1-min sustained surface wind speed of over 64 kts

- JTWC records a 1-min sustained surface wind speed
- RSMC uses a 10-min sustained wind speed



- Simiu and Scanlon (1978) suggested the strength of 10-min sustained wind is statistically 88% of 1-min sustained wind. Therefore, we use the threshold 56 kts (64 x 0.88) to detect typhoon cases in the RSMC (Knapp et al., 2010).


a.
TY counts in OND
Black: RSMC, Grey: JTWC
counts
Year
12
10
8
6
4
2
0
1979
1981
1983
1985
1987
1989
1991
1993
1995
1997
1999
2001
2003
2005
2007
2009
2011

Bayesian change-point analysis for tropical cyclones

- Given the Poisson intensity parameter (i.e., the mean seasonal TC rates), the probability mass function (PMF) of *h* typhoons occurring in *T* years is

$$P(h \mid \lambda, T) = \exp(-\lambda T)\frac{(\lambda T)^h}{h!}$$

- where $\lambda > 0$ $T > 0$ and $h = 0,1,2,\ldots$. The λ is regarded as a random variable, not a constant.

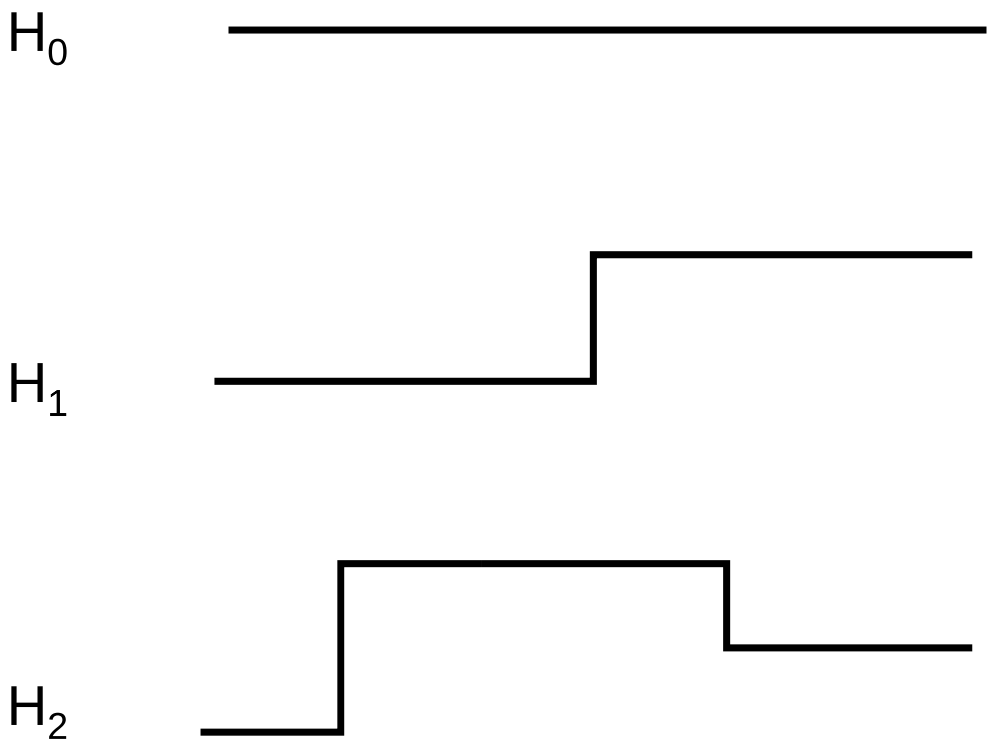
- Gamma density is known as a conjugate prior and posterior for λ. A functional choice for λ is a **gamma distribution**

$$f(\lambda \mid h', T') = \frac{T'^{h'} \lambda^{h'-1}}{\Gamma(h')} \exp(-\lambda T')$$

- where λ>0, *h´* >0, *T´*>0. *h´* and *T´* are prior parameters.

Hypothesis model for change-point analysis

(Consider 3 hypo.)



(1) Hypothesis H_0: "A no change of the rate" of the typhoon series:

$h_i \sim Poisson(h_i \mid \lambda_0, T)$, $i = 1,2,\ldots,n$.

$\lambda_0 \sim gamma(h_0', T_0')$ where the prior knowledge of the parameters h_0' and T_0' is given. $T = 1$.

(2) Hypothesis H_1: "A single change of the rate" of the typhoon series:

$h_i \sim Poisson(h_i \mid \lambda_{11}, T)$, when $i = 1,2,\ldots,\tau - 1$

$h_i \sim Poisson(h_i \mid \lambda_{12}, T)$, when $i = \tau,\ldots,n$

$\tau = 2,3,\ldots,n$, and

$\lambda_{11} \sim gamma(h_{11}', T_{11}')$

$\lambda_{12} \sim gamma(h_{12}', T_{12}')$

where the prior knowledge of the parameters h_{11}', T_{11}', h_{12}', T_{12}' is given. There are two epochs in this model and τ is defined as the first year of the second epoch, or the **change-point**.

Bayesian inference under each hypothesis

(1) Bayesian inference under H_0 hypothesis

There is only one parameter λ_0 under this hypothesis. Since gamma is the conjugate prior for Poisson, the conditional posterior density function for λ_0 is:

$$\lambda_0 \mid \mathbf{h}, H_0 \sim gamma\ (h_0' + \sum_{i=1}^{n} h_i, T_0' + n)$$

(2) Bayesian inference under H_1 hypothesis

Under this hypothesis, there are 3 parameters, λ_{11}, λ_{12} and τ.

$$P(\tau \mid \mathbf{h}, H_1, \lambda_{11}, \lambda_{12}) \propto e^{-(\tau-1)(\lambda_{11}-\lambda_{12})} \left(\frac{\lambda_{11}}{\lambda_{12}}\right)^{\sum_{i=1}^{\tau-1} h_i}$$

$$\lambda_{11} \mid \mathbf{h}, \tau, H_1 \sim gamma(h_{11}' + \sum_{i=1}^{\tau-1} h_i, T_{11}' + \tau - 1)$$

$$\lambda_{12} \mid \mathbf{h}, \tau, H_1 \sim gamma(h_{12}' + \sum_{i=\tau}^{n} h_i, T_{12}' + n - \tau + 1)$$

(2) Bayesian inference under H_1 hypothesis

Under this hypothesis, there are 3 parameters, λ_{11}, λ_{12} and τ.

$$P(\tau \mid \mathbf{h}, H_1, \lambda_{11}, \lambda_{12}) \propto e^{-(\tau-1)(\lambda_{11}-\lambda_{12})} \left(\frac{\lambda_{11}}{\lambda_{12}}\right)^{\sum_{i=1}^{\tau-1} h_i}$$

$$\lambda_{11} \mid \mathbf{h}, \tau, H_1 \sim gamma(h_{11}' + \sum_{i=1}^{\tau-1} h_i, T_{11}' + \tau - 1)$$

$$\lambda_{12} \mid \mathbf{h}, \tau, H_1 \sim gamma(h_{12}' + \sum_{i=\tau}^{n} h_i, T_{12}' + n - \tau + 1)$$

TY-count (number)	E1 [79-94]	E2 [95-11]	E2-E1	p-value	significance
OND	5.94	3.24	-2.70	0.0002	✓
Oct.	3.13	1.94	-1.19	0.0163	✓
Nov.	1.88	0.88	-1.00	0.0062	✓
Dec.	0.94	0.41	-0.53	0.041	✓
TY-lifespan (days)					
OND	6.61	4.37	-2.24	0.0039	✓
Oct.	7.80	6.18	-1.62	0.1195	
Nov.	7.11	3.64	-3.47	0.0112	✓
Dec.	4.92	3.28	-1.64	0.1056	
TY-ACE (10^3 m^2s^{-2})					
OND	32.69	21.20	-11.49	0.0029	✓
Oct.	40.66	31.50	-9.16	0.1552	
Nov.	36.82	17.36	-19.46	0.0024	✓
Dec.	20.58	14.73	-5.85	0.0843	

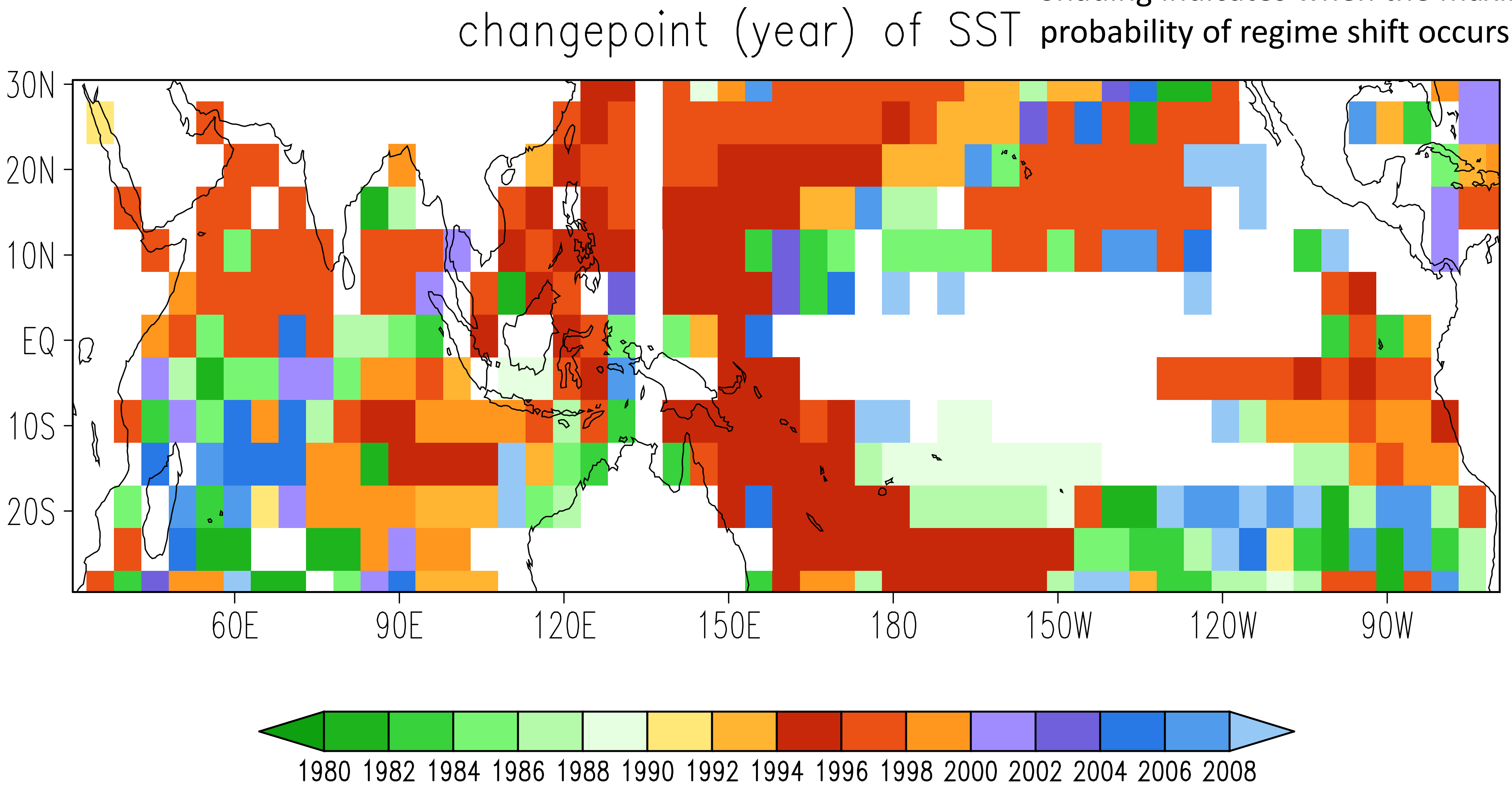
Wilcoxon-Mann-Whitney test

The abrupt shift in the NWP typhoon counts could be linked to the tropical SST variability that influences atmospheric/oceanic conditions for typhoon genesis.

Is there an abrupt shift in the SST time series?

- The SST data follow a Gaussian distribution, not a Poisson process
- For the Gaussian process, the two parameters, mean and variance, are assumed to change with time. The conjugate prior for the mean is also Gaussian and the conjugate prior for the variance is the inverted gamma.

Late-season during 1979-2011
Shading indicates when the maximum probability of regime shift occurs



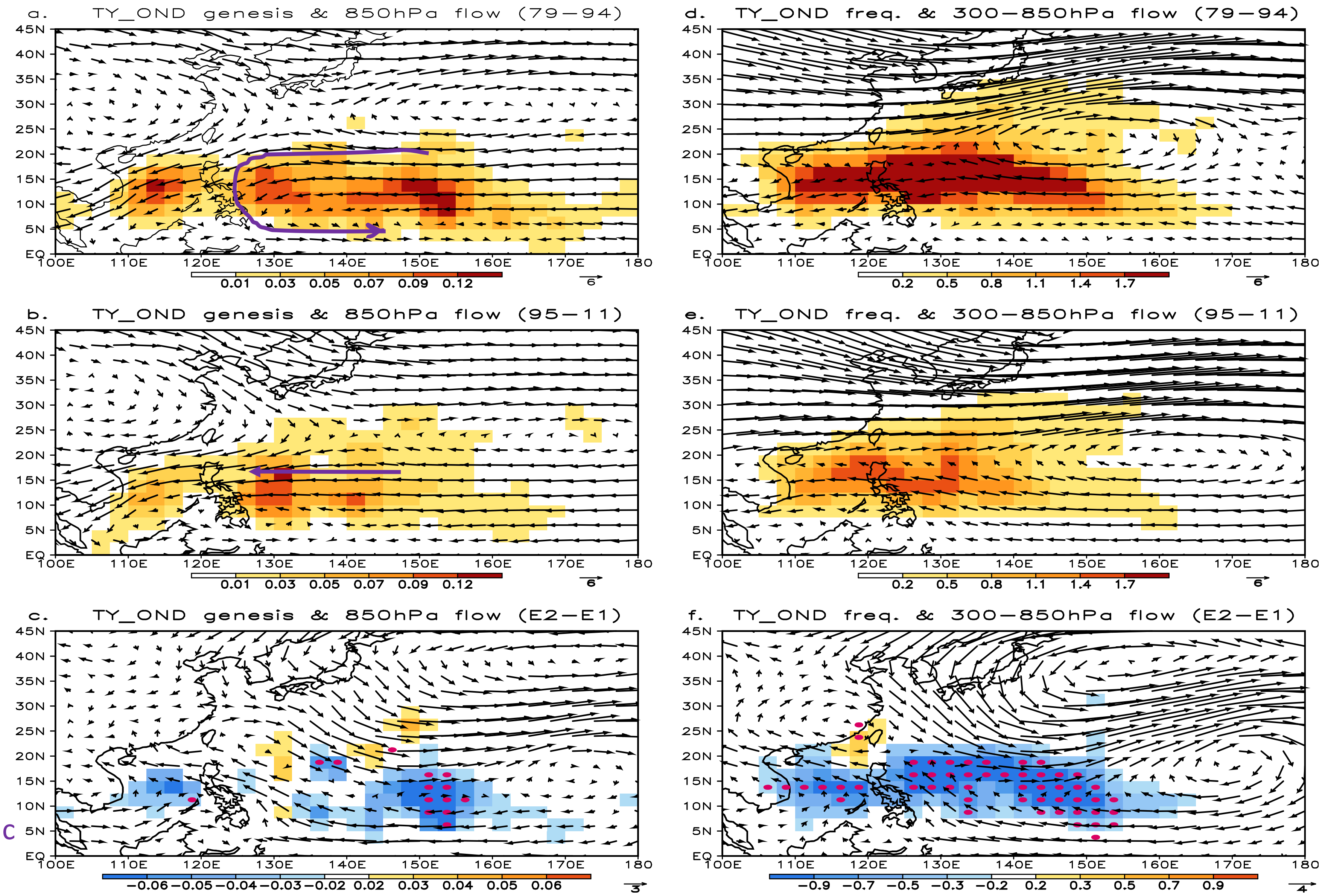
OND

Genesis freq and 850 hPa wind, E1

Genesis freq and 850 hPa wind, E2

E2 – E1

Weakened cyclonic circulation (anticyclonic anomaly)



ERA Interim

Passage freq and steering flow, E1

Passage freq and steering flow, E2

E2 – E1

Significant decrease over WNP and SCS from E1 to E2, but a small Increase near Taiwan

Epochal changes in TC genesis potential index

$$\mathrm{GPI} = \left|10^5 \eta\right|^{3/2} \left(\frac{\mathrm{RH}}{50}\right)^3 \left(\frac{V_{\mathrm{pot}}}{70}\right)^3 \left(1 + 0.1 V_s\right)^{-2} \left(\frac{-\omega + 0.1}{0.1}\right)$$

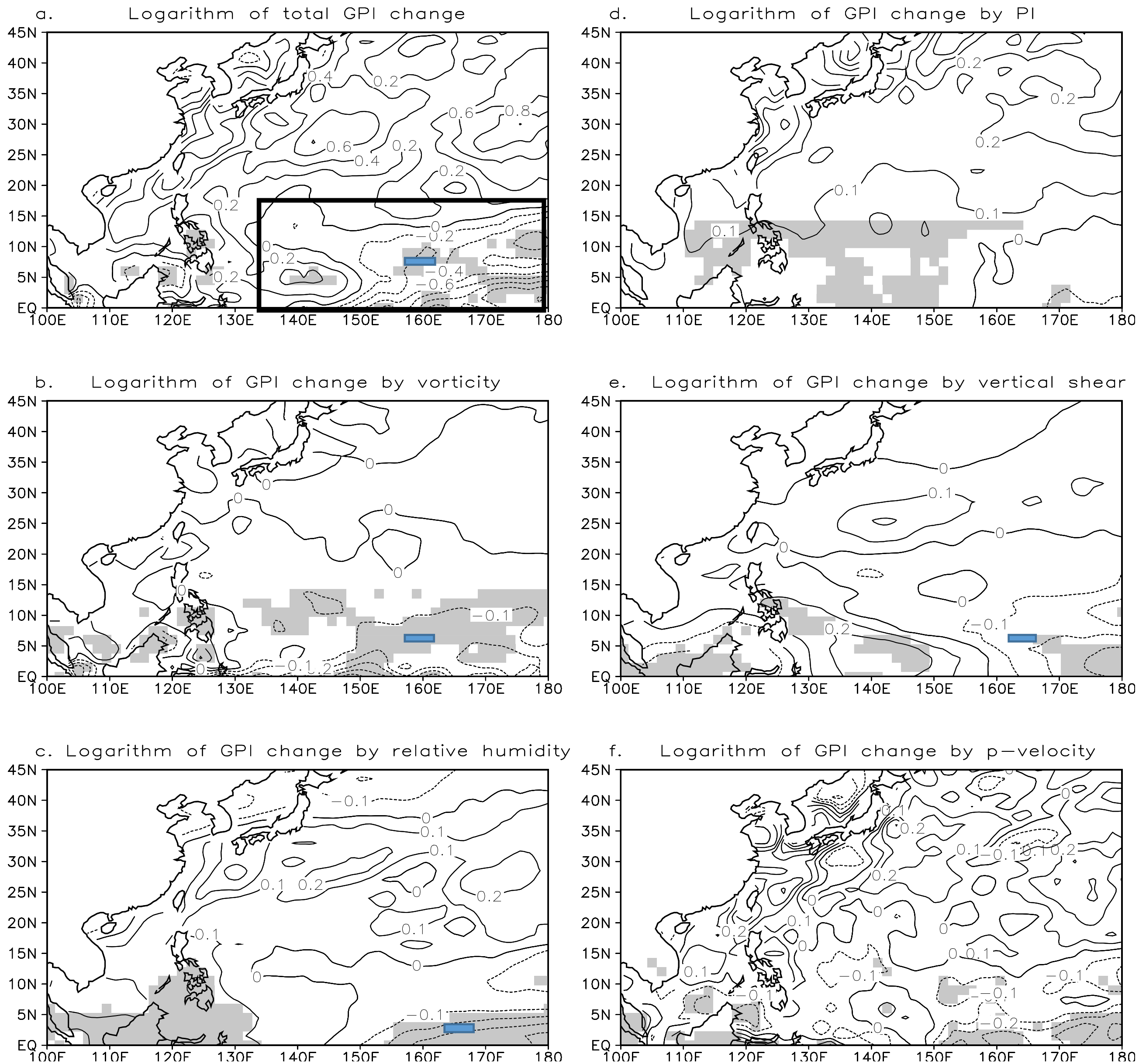
By taking the log in the GPI equation, the sum of the five variational GPI changes on the right-hand side is identical to the total GPI change

Log GPI values
E2 – E1

Total GPI change

GPI change by vorticity

GPI change by relative humidity



GPI change by PI

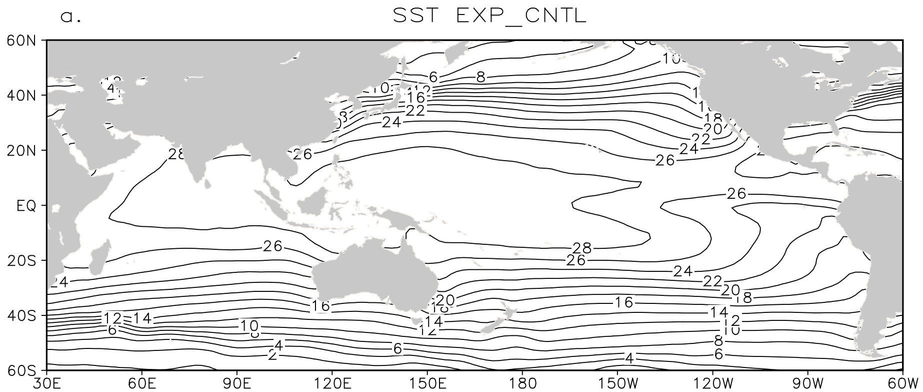
GPI change by VWS

GPI change by p-velocity

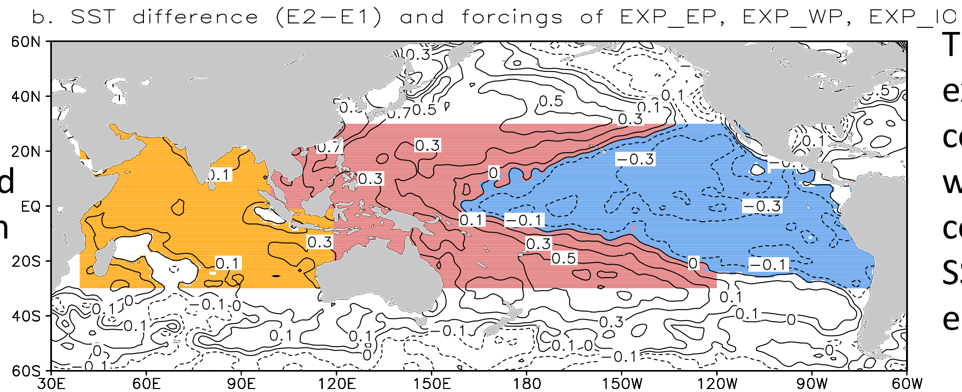
Area average (135-180E, 0-17.5N)	GPI	VORT	RH	PI	VWS	OMEGA
Value (percent contribution)	-0.25 (100%)	-0.11 (44%)	-0.06 (24%)	0.03 (-12%)	-0.05 (20%)	-0.06 (24%)

MRI-AGCM (Japan)

EXP_CNTL: Global OND-mean SST in E1



EXP_EP+WP+IO: SST differences between 2 epochs are added to the SST field in EXP_CNTL



Three additional experiments are conducted, forced with SST in the control run with SST anomalies in each of 3 basins

- To increase the robustness, ensemble simulations with initial conditions on the 1st of November in five different years are used. All of the simulations are integrated for a period of ten years after an initial spin-up of a few months. The simulated results shown are averages of five ensemble runs for each experiment.

GPI changes

Vorticity differences

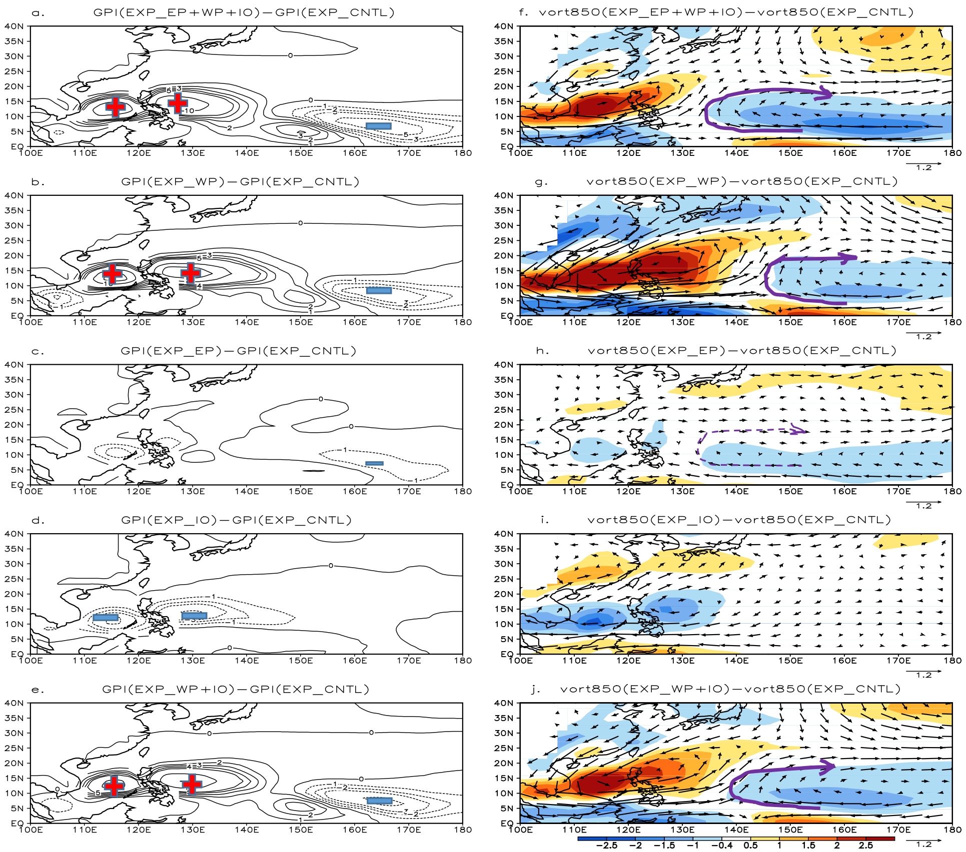
(EXP_EP+WP+IO) – (EXP_CNTL)

(EXP_WP) – (EXP_CNTL)

(EXP_EP) – (EXP_CNTL)

(EXP_IO) – (EXP_CNTL)

(EXP_WP+IO) – (EXP_CNTL)



Summary

- An abrupt shift in the late-season (OND) typhoon activity occurs in 1995, and a similar change also occurs in the OND SST series over the western Pacific, eastern North Pacific, and north Indian Ocean.
- Typhoon counts, lifespans, and ACE of the late-season during 1995-2011 epoch decreased significantly relative to that of 1979-1994 (e.g., late-season typhoons tend to be short-lived in recent decades).
- Significant decrease in typhoon passage frequency from E1 to E2 over the WNP and SCS, but a small increase near Taiwan (more typhoons)
- The negative vorticity anomaly plays a major role to the total GPI decrease over the southeast WNP during the recent epoch.
- Numerical simulation experiments indicate that the western Pacific warming in the recent epoch is more important than eastern Pacific cooling for the variations of GPI and circulation.


Thank You!