

[2019년 9월 기록적인 태풍 영향의 원인규명 연구]

Has global warming contributed to the largest number of typhoons affecting Korea in September 2019?

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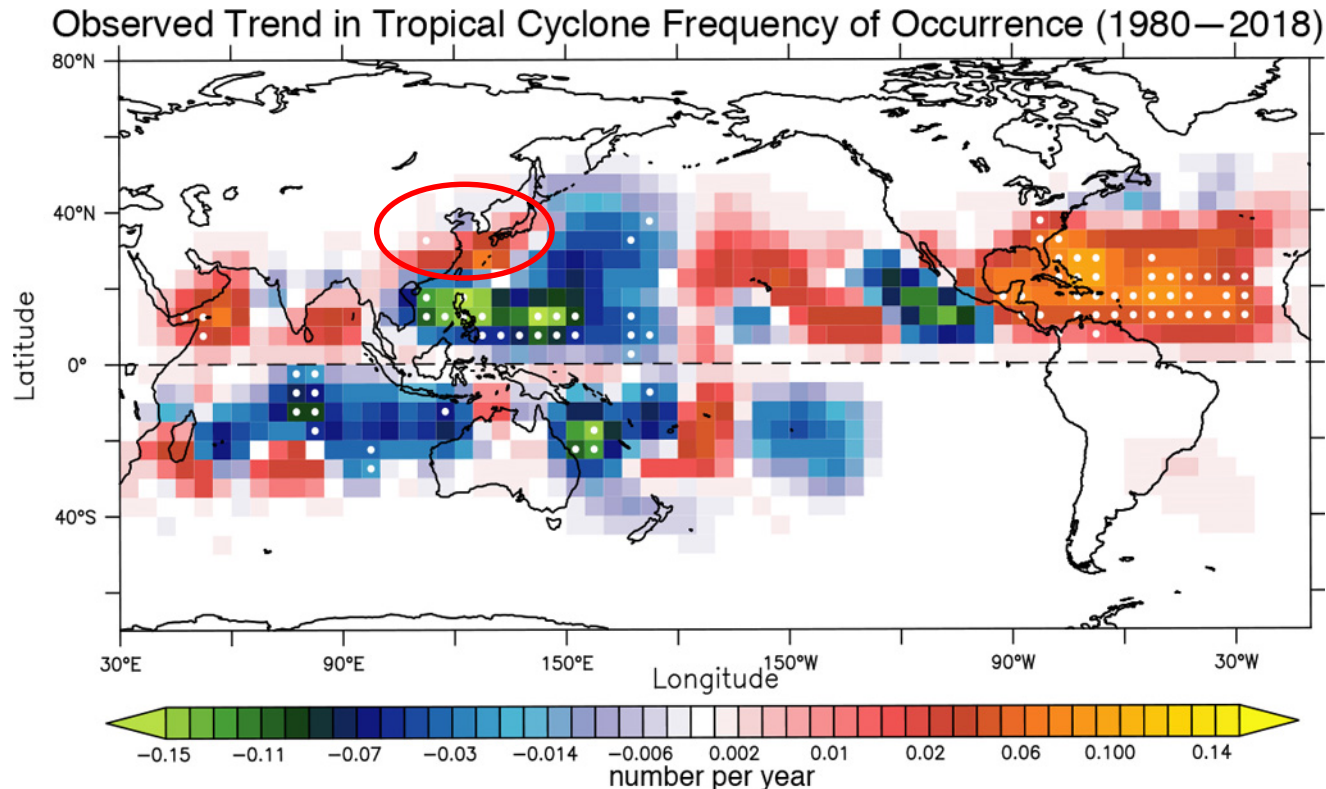
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(Min et al. 2021, BAMS)

Global changes in tropical cyclone frequency (1980-2018)

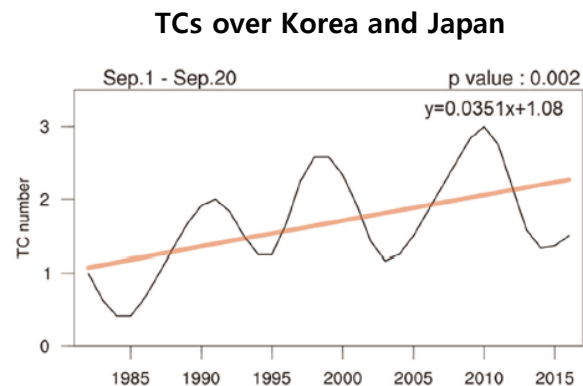
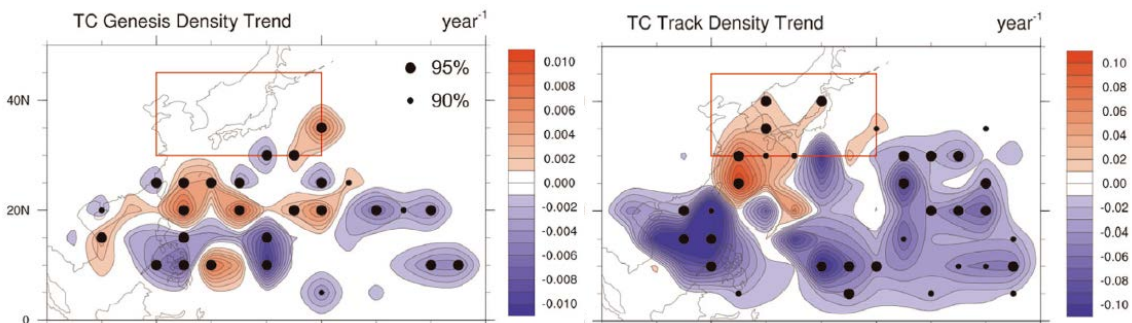


- “The number of TCs originating in the North Atlantic and central Pacific has increased over the past four decades, while fewer have occurred in the southern Indian Ocean and western North Pacific”
- **Weak increase over East Asia**

Murakami et al. (2020)

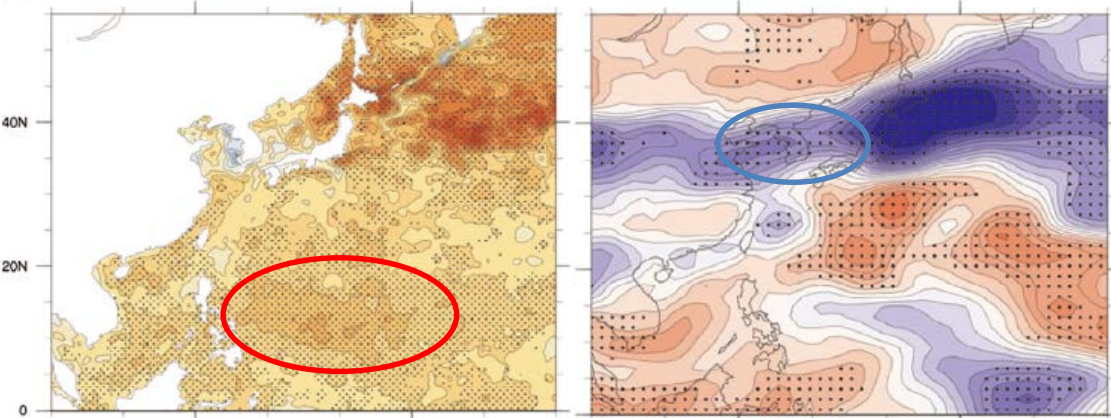
More September TCs affecting Korea?

Lee et al. (2016)



Sea Surface Temperature (K year⁻¹)

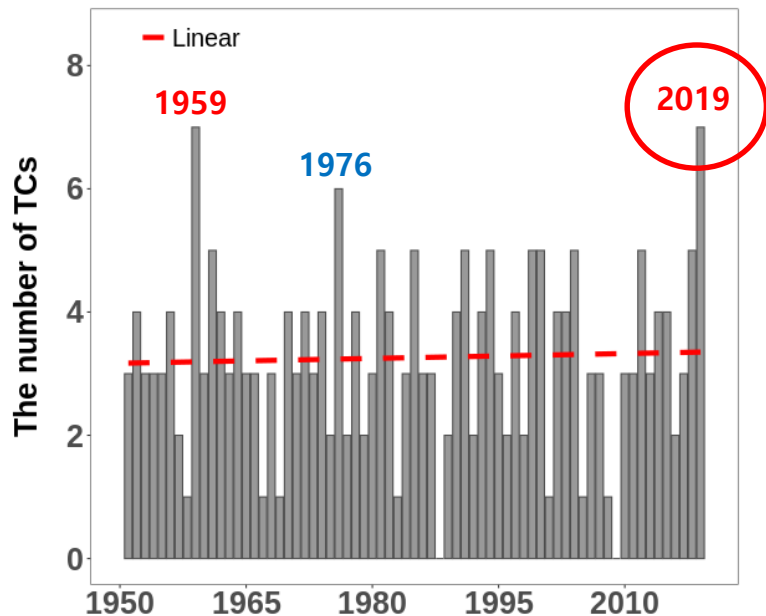
Vertical Wind Shear (m s⁻¹ year⁻¹)



- September 1st-20th during 1982-2016
- TC genesis region shifted northward
- More TCs affecting "Korea and Japan"
- **SST increase** in the western North Pacific, and **vertical wind shear decrease** in the mid-latitudes (30-40°N) provided favorable conditions to maintain the TC intensity

Annual number of typhoons affecting Korea

Annual (1951-2019)



KMA report (1904-2019)

Number of TCs	Year
7	1950, 1959 , 2019
6	1914, 1933, 1976

- Long-term trends are insignificant
- Years with 6~7 TCs are rare

- 부쩍 잦아진 '가을 태풍'...한국 올해 처음으로 9월 3차례 태풍
- 링링·타파 이어 미탁까지...기상청 "기후변화 말고는 설명 안 돼"

역대 한반도에 영향 준 태풍 수

2000년 이후 발생 태풍 5개 이상 기준



* 제18호 태풍 '미탁' 포함 (한반도 영향 예상)

이전 한반도에 영향을 가장 많이 미친 태풍 수

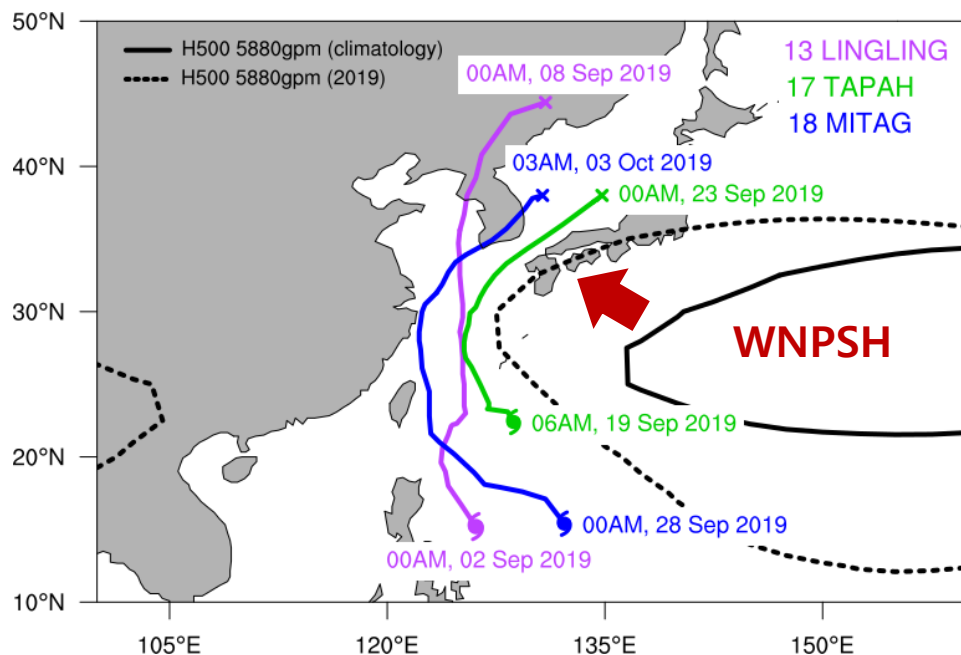


자료/ 기상청



김영은 기자 / 20190930

2019 September typhoons affecting Korea

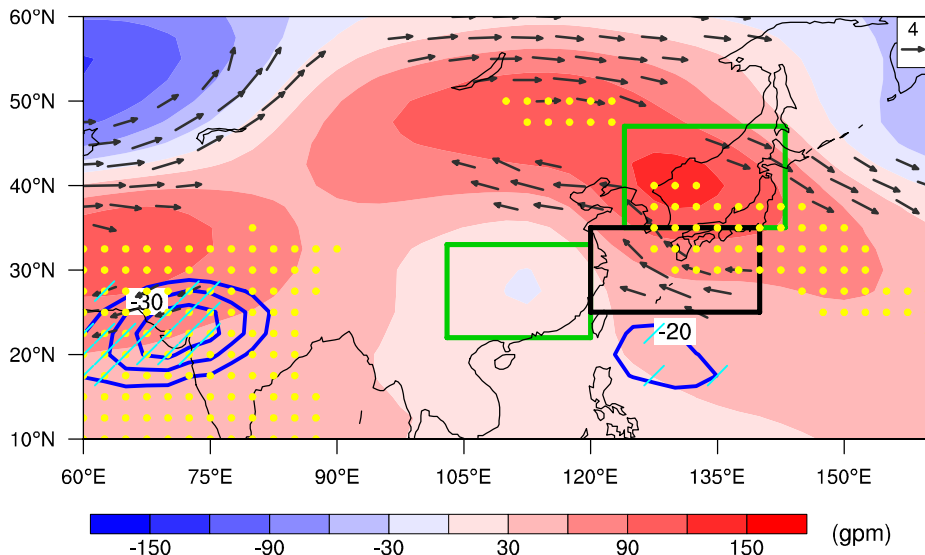


- **Three TCs struck Korea** (first time since 1904)
- Contributed to **record high (seven) TCs in 2019** since 1959
- **Unusually strong WNP subtropical high with an extreme northwest shift**

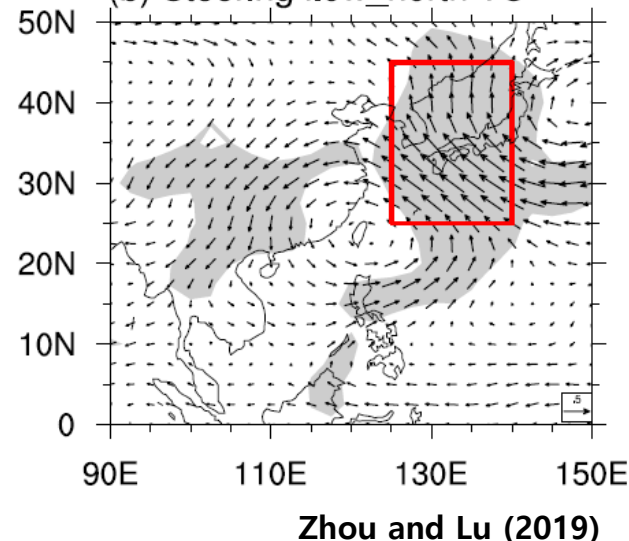


'Extreme' circulation pattern in September 2019

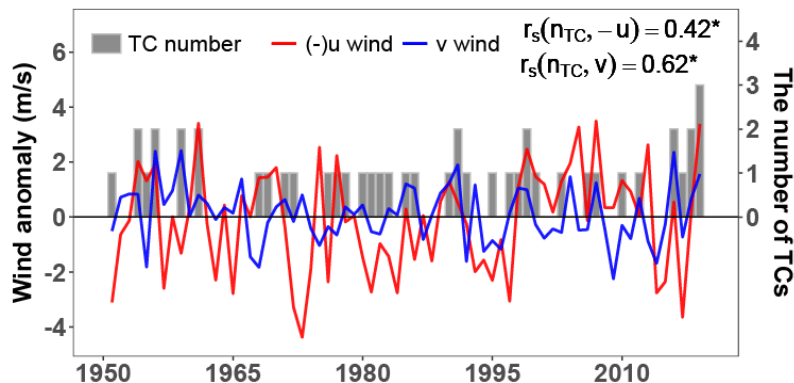
H200 anomaly (2019)



(b) Steering flow_north TC



Steering wind and TC number



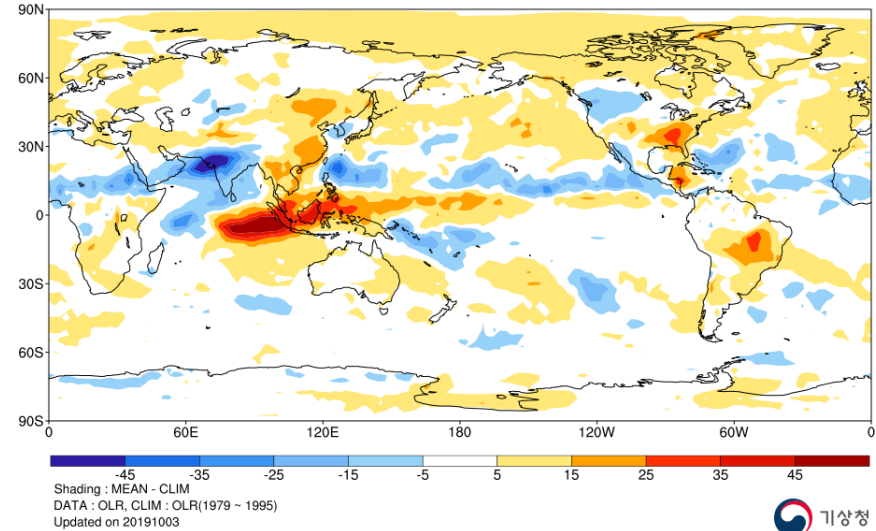
- **Record high anti-cyclonic circulation over northeast Asia**, which intensified southeasterly steering winds
- **G200 (H200 gradient between East Sea region and southern China)** defined as proxy for steering flow [$r_s(n_{TC}, G200) = 0.49^*$]

Strong Indian monsoon in 2019 September...

印 9월 강우량 102년만에 최대...
"북부 집중호우로 120여명 사망"

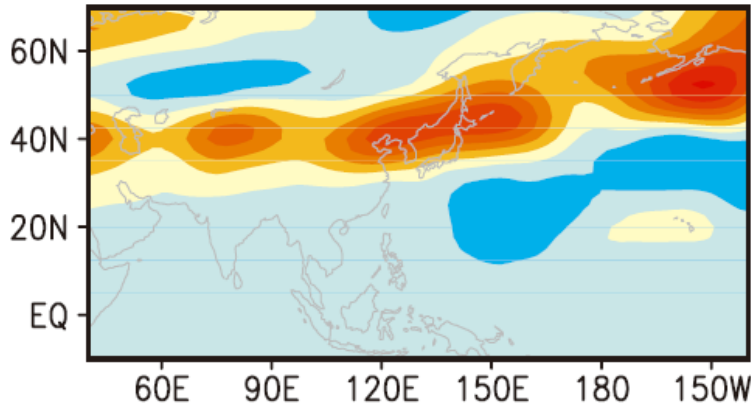


Outgoing Longwave Radiation Anomaly
01Sep2019 ~ 30Sep2019



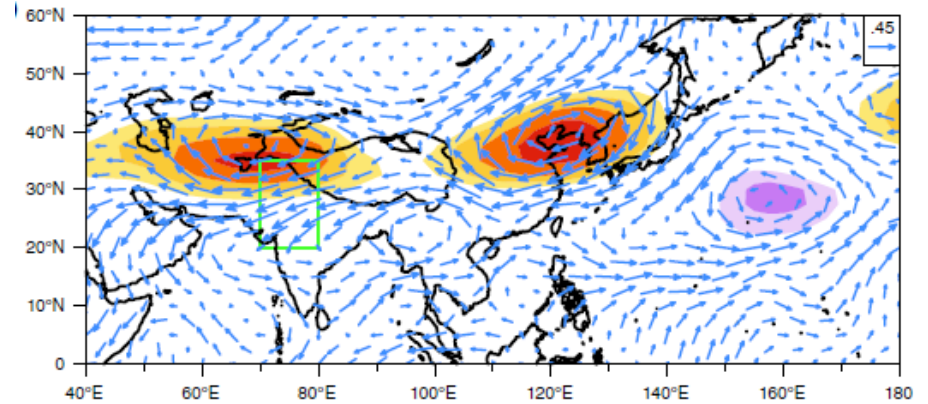
- **Extremely strong Indian monsoon** and its delayed withdrawal during September 2019
- **Any influence on TCs affecting Korea?**

Composite (OLR>0.5SD) July-August



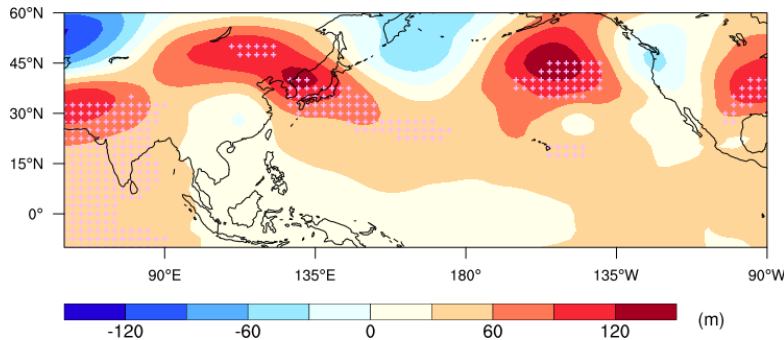
Min et al. (2020)

Correlation (IMRI & H250) July-August



Kim et al. (2019)

H200 anomaly (2019 September)



- Northwest India convection **induces anomalous high pressure over Korea** during summer, contributing to heat wave (CGT-like pattern)
- Similar pattern observed in Sep. 2019** due to the record delayed Indian monsoon

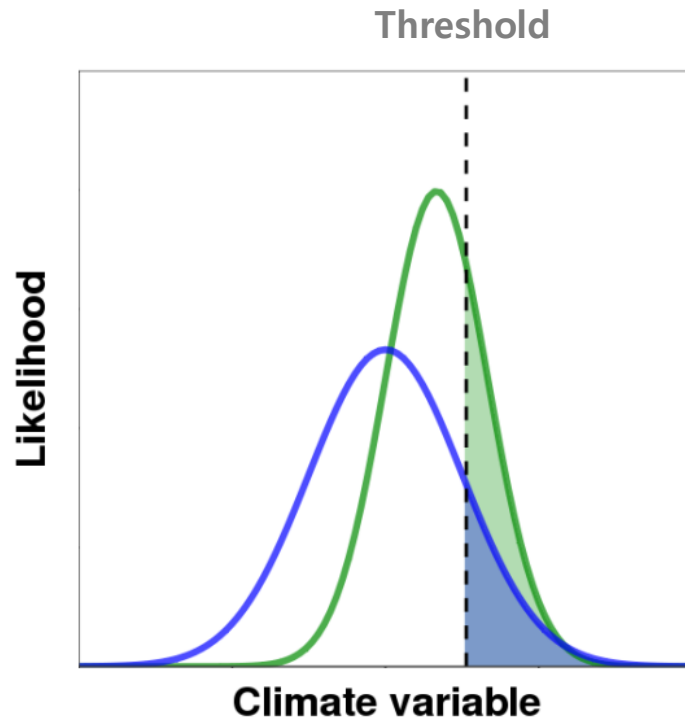
This study examines human and natural contributions to the 2019 atmospheric circulation patterns conducive to the record high typhoon affecting Korea

- 1) Human influence: mainly greenhouse gas increases**
- 2) Natural variability: Northwest (NW) Indian convection**

- Using CMIP6 multi-model dataset (CGCM) and HadGEM3-A large-ensemble simulations (AGCM)
- **Comparing probabilities of occurrence of the TC-related circulation patterns**

Method: Risk ratio analysis

- Comparing the probability of extreme events occurring in a **real world (with human influence)** with that in a **counterfactual world (without human influence)**
- Calculating RRs for strong versus weak tropical convection cases ($RR = P_{sc} / P_{wc}$)**



$$RR = P_A / P_N$$

- P_A : Probability estimated in **anthropogenic forced conditions (ALL)**
- P_N : Probability that extremes will occur exceeding the observed strength in **natural unforced conditions (NAT)**
- RR confidence intervals : likelihood ratio method (Paciorek et al. 2018)

- Observations: GPH, horizontal wind (NCEP1), OLR (NOAA interpolated), Precipitation (GPCP)

❖ CMIP6 (2010-2019)

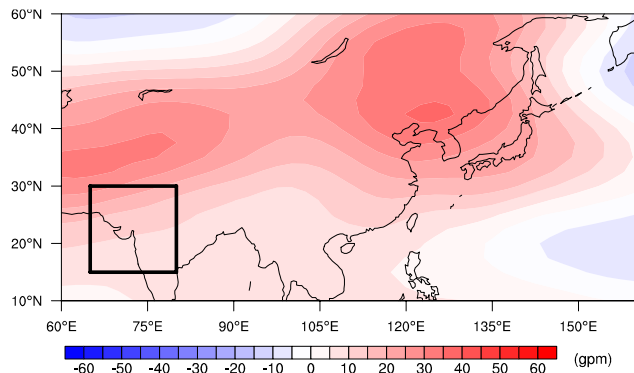
Model	ALL	NAT	GHG
BCC-CSM2-MR	1	1	1
CanESM5	10	10	10
CNRM-CM6-1	6	6	6
GFDL-ESM4	1	1	1
HadGEM3-GC31-LL	4	4	4
IPSL-CM6A-LR	6	6	6
MIROC6	3	3	3
MRI-ESM2-0	3	3	3
NorESM2-LM	3	3	3
Total	9 models (37 runs; 370 samples)		

❖ HadGEM3-A-N216

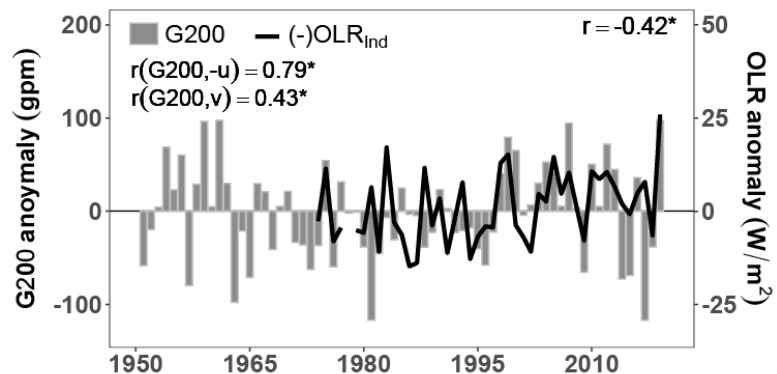
Experiment	ALL	NAT
External forcing	GHG: historical Aerosol: historical Land use: historical	GHG: pre-industrial Aerosol: pre-industrial Land use: pre-industrial
Boundary condition	Prescribed observed SST and sea ice concentrations (HadISST v1)	Prescribed adjusted SST and SIC with anthropogenic influences removed (delta-SST) from HadISST • 5 Delta-SST (ALL-NAT from 4 CMIP5, HadISST linear fit from 1870)
Period	2019	2019
# of runs	525	525 (105 samples for each delta-SST patterns)

Model performance for teleconnection pattern (1981-2010)

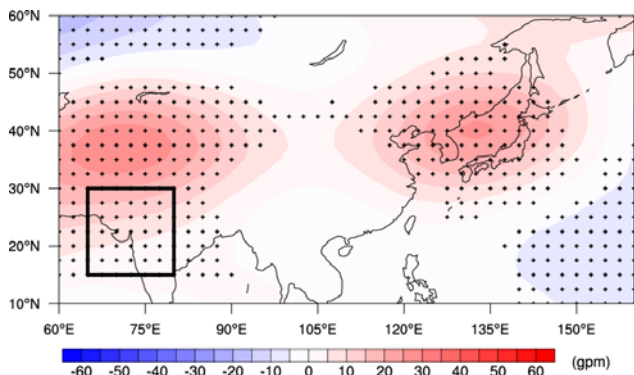
H200 (NCEP1, OLR \leq 30%)



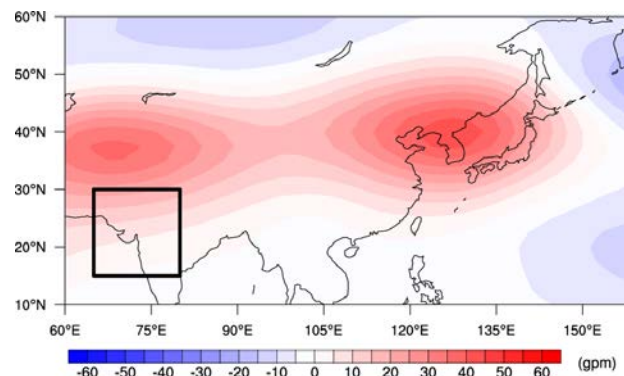
Time series of G200 & OLR (NCEP1)



CMIP6 (OLR \leq 30%)

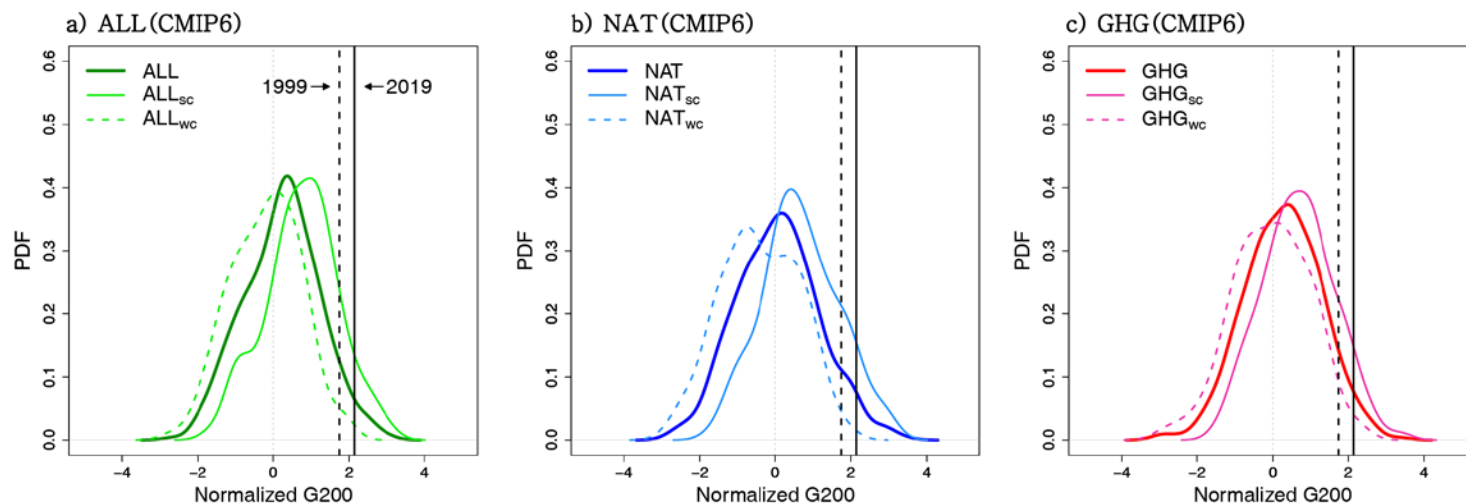


HadGEM3-A-N216 (PR \geq 70%)



- G200 is correlated with NW India convection in OBS ($r = -0.42^*$)
- Models well capture the observed teleconnection pattern

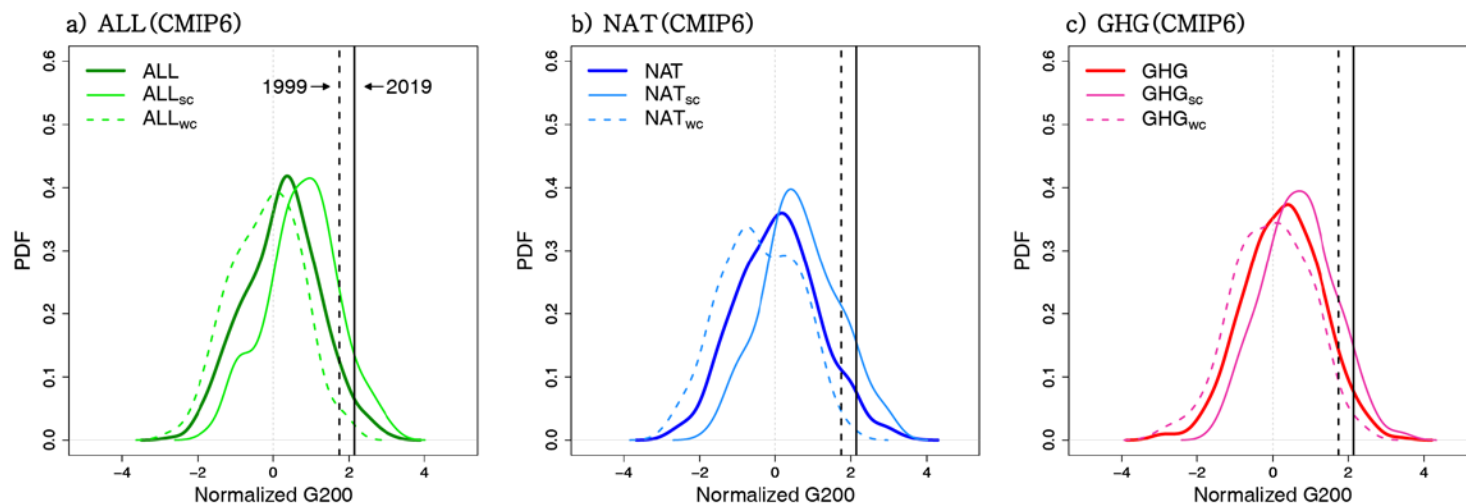
Extreme G200 probability: CMIP6 runs



Year	Forcing	P_{TOT} (%)	P_{SC} (%)	P_{WC} (%)	$RR_{SC/WC}$	$RR_{ALL/NAT}$
2019	ALL	2.97	7.27	0.00	∞ [5.49- ∞]	0.92 [0.46-1.81]
	NAT	3.24	8.11	0.00	∞ [6.24- ∞]	
	GHG	2.97	5.41	1.80	3.00 [0.89-14.02]	

- **Similar probability of extreme G200** occurrence across ALL, NAT, and GHG, indicating **weak human influences on TC-related circulation patterns**
- **Strong NW Indian convection increases probability of extreme G200 more than three times**

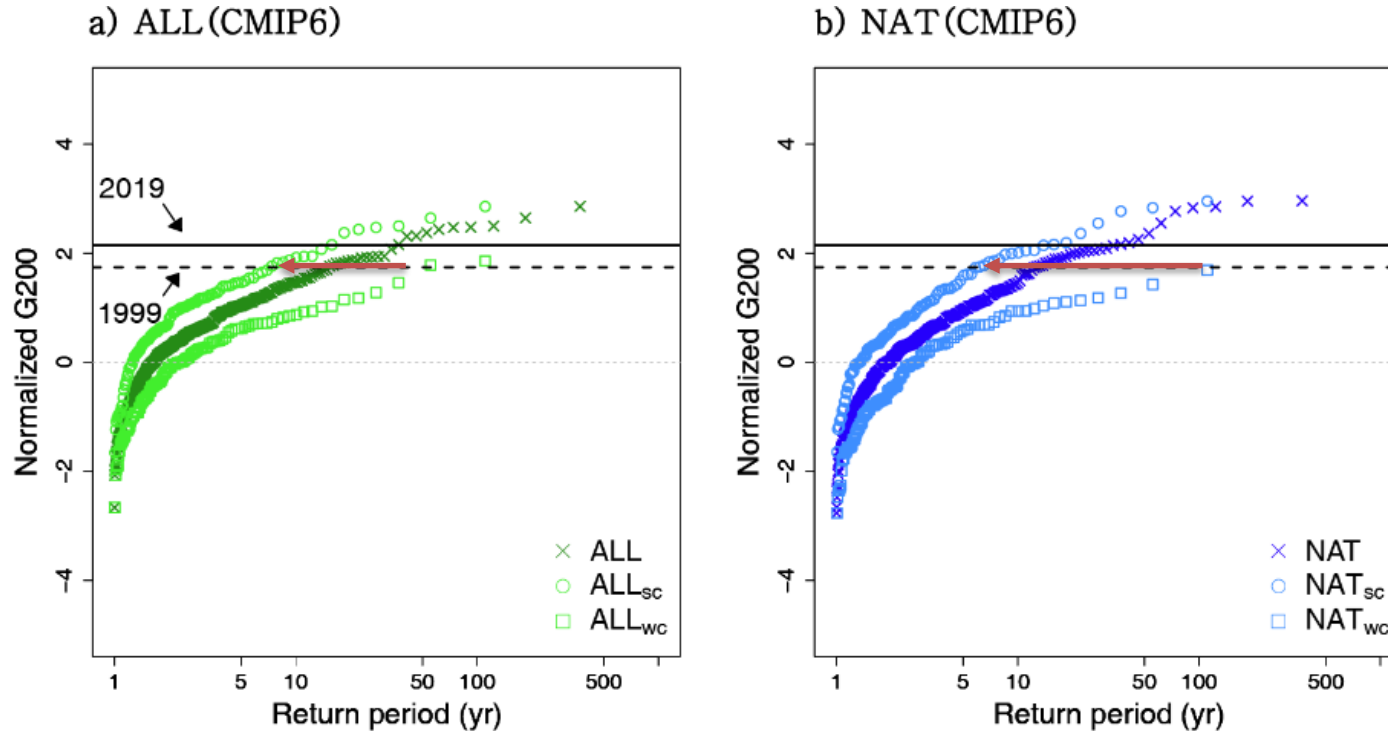
Extreme G200 probability: CMIP6 runs



Year	Forcing	P_{TOT} (%)	P_{SC} (%)	P_{WC} (%)	$RR_{SC/WC}$	$RR_{ALL/NAT}$
1999	ALL	6.76	14.41	2.70	5.33 [2.15-17.17]	0.83 [0.54-1.28]
	NAT	8.11	17.12	0.90	19.00 [4.97-182.47]	
	GHG	7.30	14.41	2.70	5.33 [2.15-17.17]	

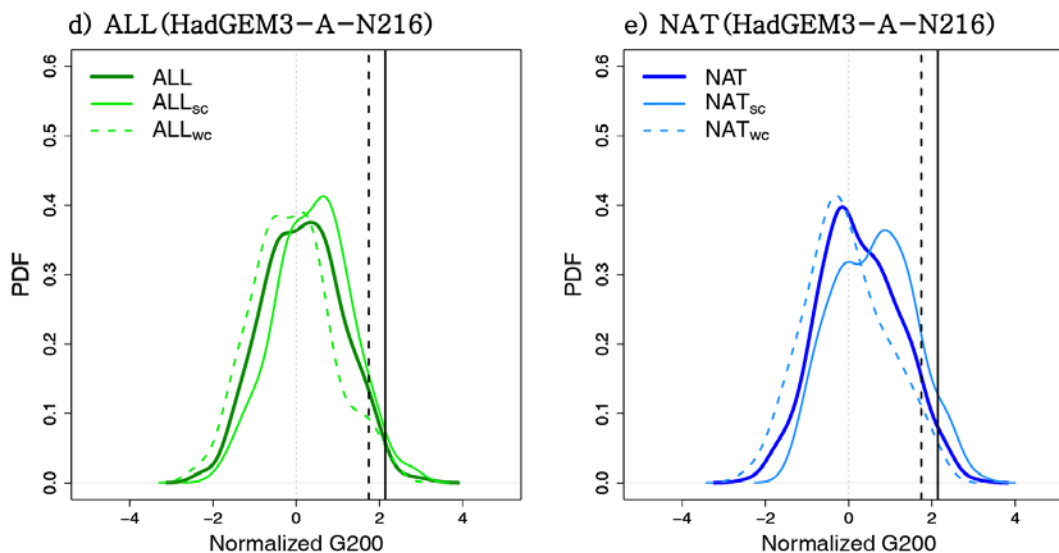
- Consistent results are obtained when applying the observed G200 from 1999 as a threshold (when we have two TCs)

Return period: CMIP6



- **Strong NW Indian convection reduces return periods of extreme G200** from 37 years to 7 years (ALL) and from 111 years to 6 years (NAT) based on 1999 value

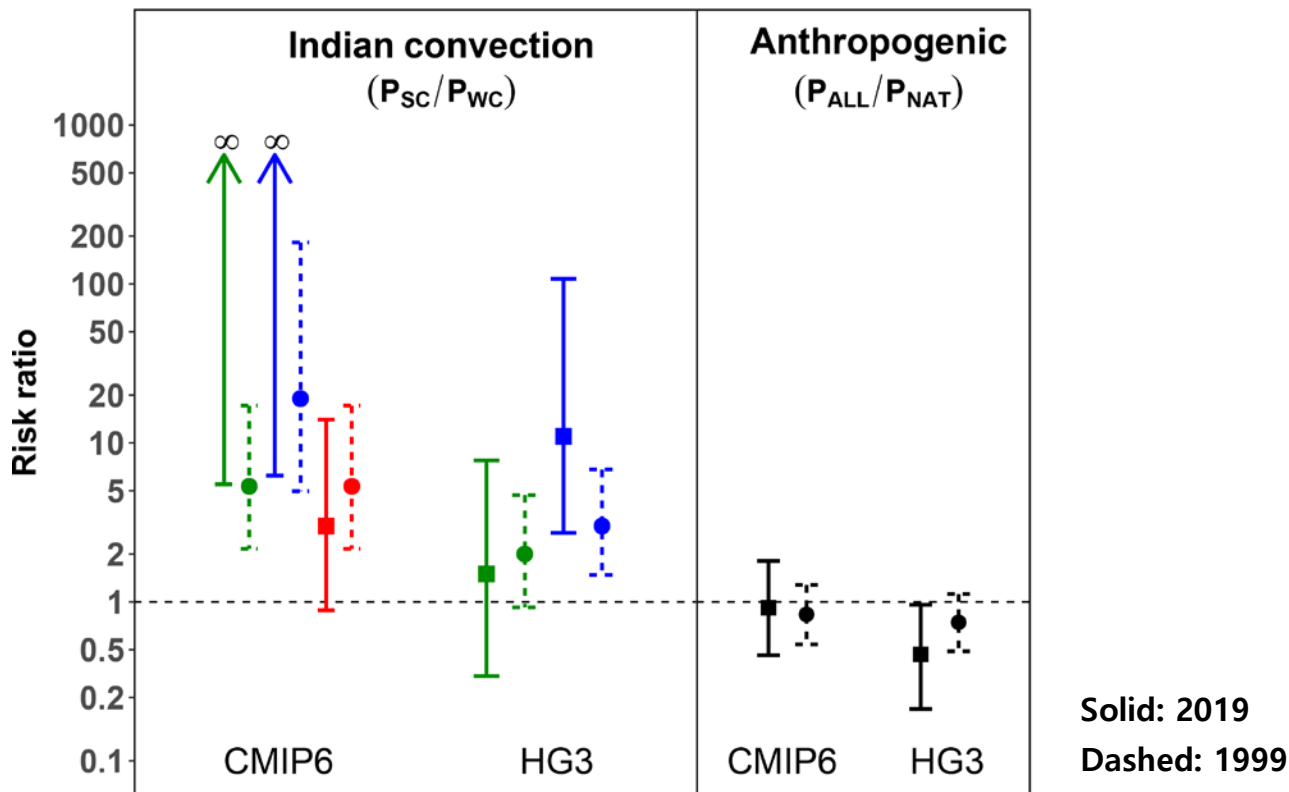
Extreme G200 probability for HadGEM3-A-N216



Year	Forcing	P_{TOT} (%)	P_{SC} (%)	P_{WC} (%)	$RR_{SC/WC}$	$RR_{ALL/NAT}$
2019	ALL	1.33	1.90	1.27	1.50 [0.34-7.76]	0.47
	NAT	2.86	6.96	0.63	11.00 [2.71-107.64]	[0.21-0.96]
1999	ALL	4.95	7.59	3.80	2.00 [0.92-4.70]	0.74
	NAT	6.67	11.39	3.80	3.00 [1.47-6.80]	[0.49-1.12]

- Similar results to CMIP6, supporting the important role of tropical convection
- Lower RRs (at least 1.5 times) due partly to narrower ensemble spread (single SST prescribed)

Risk ratio summary



- NW India convection increases probability of favorable circulation pattern conducive to typhoon affecting Korea
- Weak influence of anthropogenic forcing (global warming)

- ❑ Our multi-model event attribution analysis indicates **no discernible anthropogenic influences on the 2019 September extreme steering winds** over the East China Sea region, which were closely associated with the record high typhoon affecting Korea.
- ❑ It is rather found that the **unusually strong September monsoon over NW India has likely contributed to the extreme circulation patterns** with increased probabilities at least 3 times in CMIP6 models and about 1.5 times in the HadGEM3-A-N216 ensemble.
- ❑ Further investigation is warranted to better understand details of how anomalous NW Indian convection induces extreme circulation patterns over the northeast Asia and also to quantify human and natural contribution to the intensified Indian monsoon.