2019 International Workshop on Climate Change: TCCIP2019
October 22-24, 2019 (Taipei)

Future Changes in a Tropical cyclone in the Midlatitude Regions: Downscaling simulations from d4PDF data using a 4-km-mesh nonhydrostatic model

TOUGOU-C

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Background

- TC translation speed has decreased over the period 1949-2016 (, particularly, in the WNP and latitudes higher than 25N)

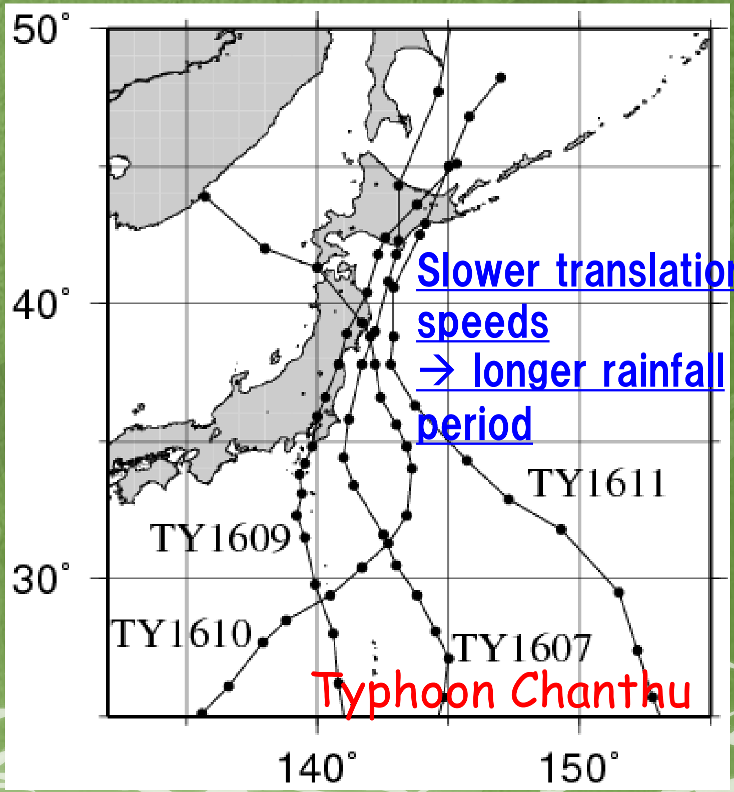
→**suggested potential changes in local rainfall totals in the warming climate** (Kossin 2018)

- PGW experiments on Typhoon Chanthu (2016) indicate that, in the warming climate,

✓ **the typhoon traveled northward at relatively slow translation speeds**

✓ **more rainfall for longer period**

(Kanada et al. 2017)



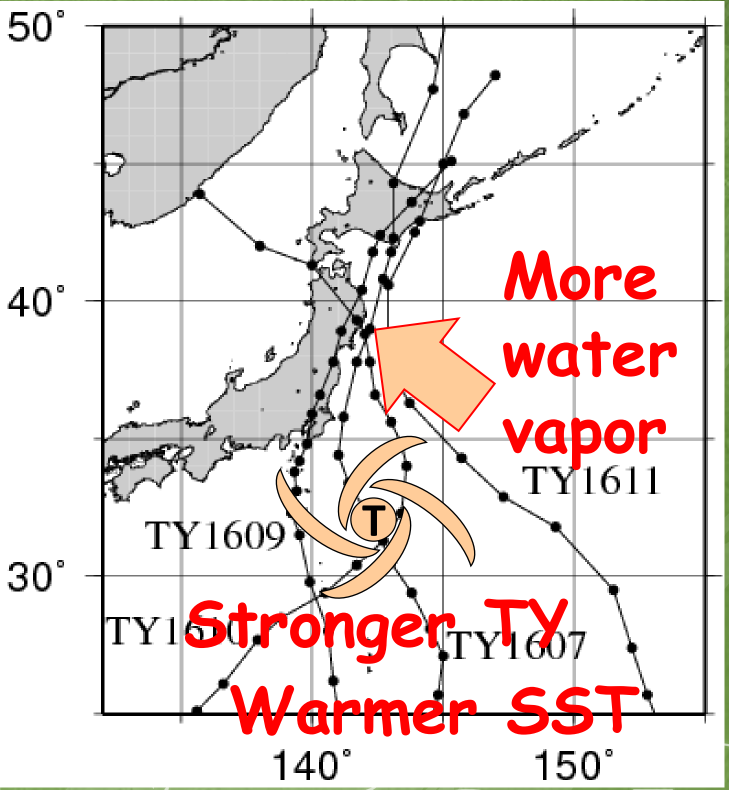
Objective

Goal: To understand the impact of global warming on a TC in the midlatitude regions

- **Typhoons that travel over the WNP along Japan** as examples of TCs in the midlatitude regions
- **d4PDF**

The database made from a huge number of ensemble simulations for **the historical (6000 years)** and **future (5400 years) climates** for Policy Decision making for Future climate change (Mizuta et al. 2017, BAMS).

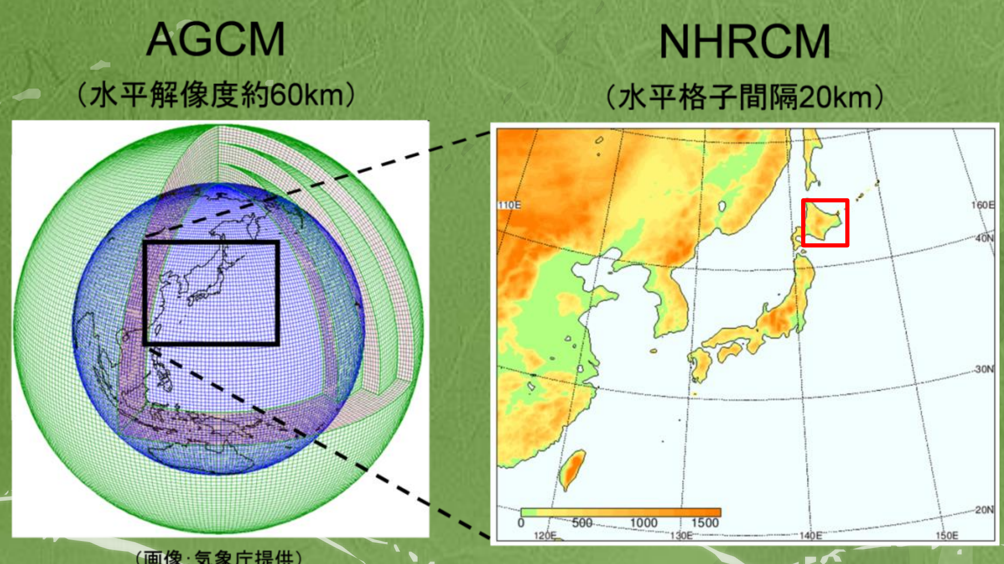
- **DDSs by a 4km-mesh non-hydrostatic model (CReSS04)**



d4PDF dataset and Method

d4PDF: Database for Policy Decision-Making for Future Climate Change

Databases produced by an unprecedentedly large ensemble of climate simulations with **a 60 km atmospheric general circulation model (AGCM60)** and dynamical downscaling with a 20 km regional climate model (NHRCM20) **to obtain probabilistic future projections of <u>low-frequency local-scale events</u>**.



Method:

1. All the WNP-TCs that travel over the sea along Japan (and pass across the red-box region) are extracted.
2. All targeted typhoons were DDS by CReSS.

Results (1): AGCM60

Four sets of AGCM60-experiments;

- historical climate simulation (HPB):

  1951-2010, 100 members → 6,000 years

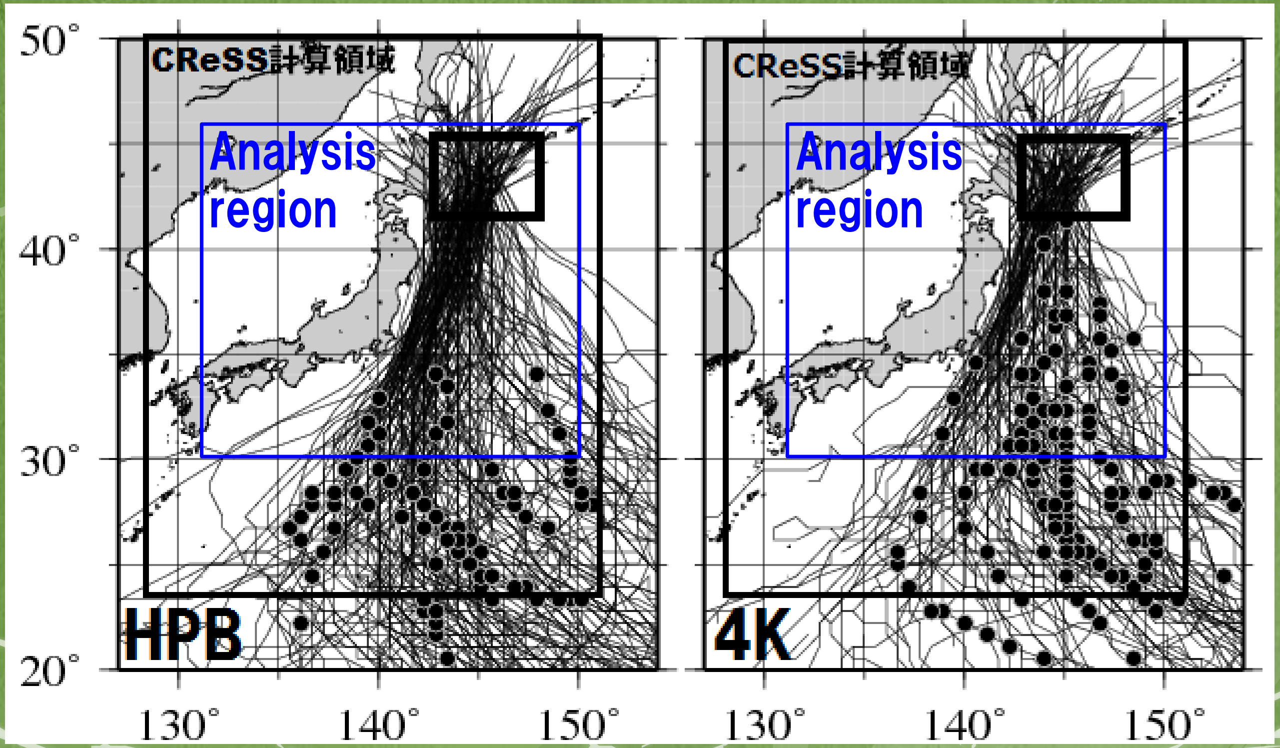
- non-warming simulation: 1951-2010, 100 members
- +2K future climate simulation: 2031-2090, 54 members
- +4K future climate simulation (4K):

  2051-2110, 90 members → 5,400 years

Frequencies and tracks of the targeted TYs

Table 1 Ensemble years and frequencies of the targeted typhoons. Those in the Regional Specialized Meteorological Center Tokyo best-track data between 1951 and 2017 were indicated by BT.

	Ensemble years	Total frequency	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.
BT	67	**8**	0	0	1	1	6	0	0
HPB	6000	**187**	1	0	2	45	84	49	6
4K	5400	**125**	0	0	1	26	63	32	3



Tracks of targeted TCs with the analysis region. Dots indicate MCP < 910hPa

Mean characteristics of the targeted TYs

Table 2 Mean minimum central pressure (MCP30), the latitude of MCP30 (Latmcp30), and northward translation speed (Vn) of the targeted typhoons in the analysis region.

		All	Jul.	Aug.	Sep.
MCP30	HPB	954	958	956	949
(hPa)	4K	945**	948*	946**	941**
Latmcp30	HPB	34.3	32.5	34.8	35.2
(Deg.)	4K	34.8*	33.0	35.0	35.5
Vn	HPB	0.30	0.23	0.27	0.39
(Deg.h-1)	4K	0.26**	0.24	0.22**	0.33**

** : 95% significant by two-sided t-test, * : 90% significant by two-sided t-test

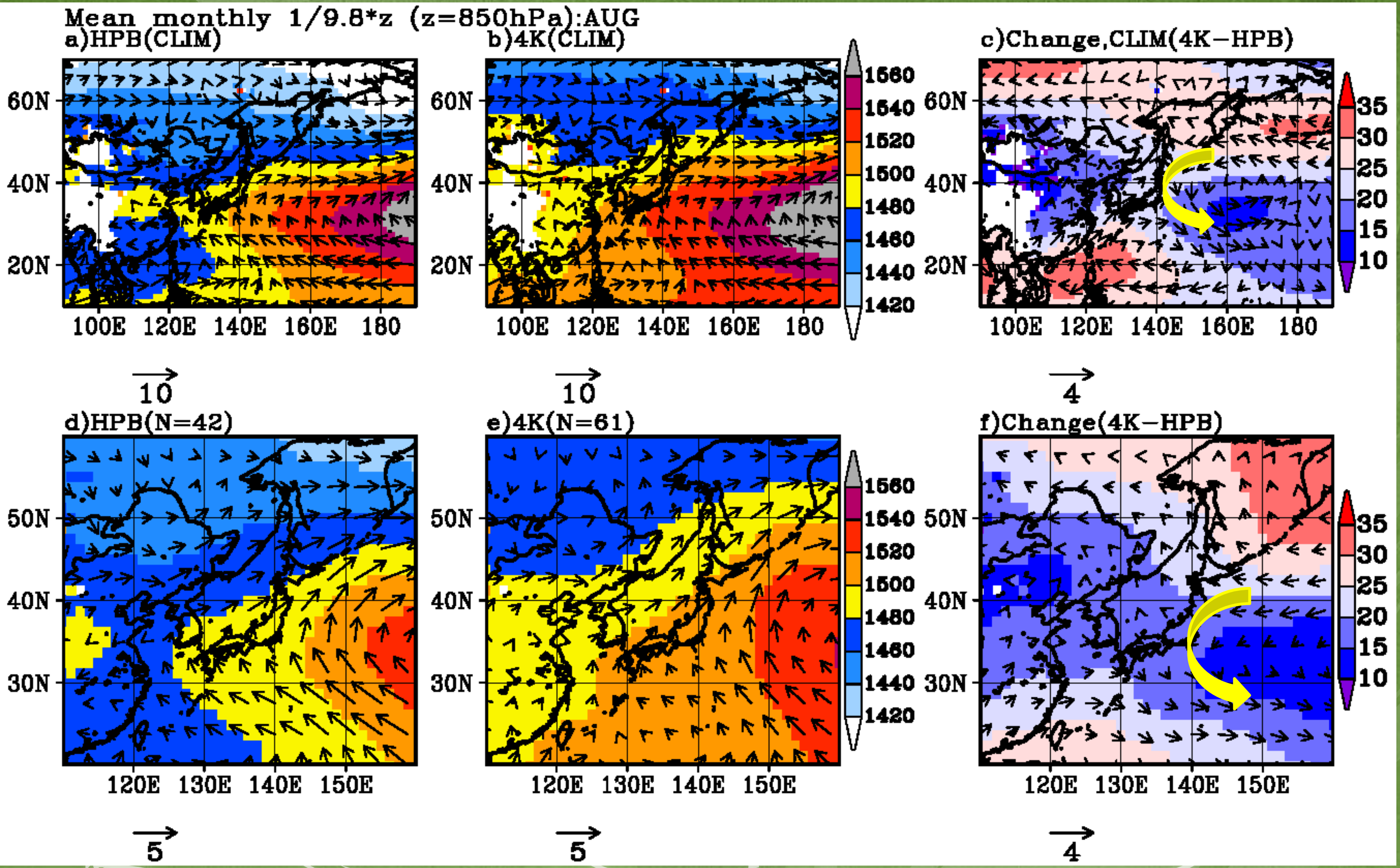
In the 4K climate,

- Mean intensity → **Increases**
- Latitude of MCP30 → **Shifts northward**
- Northward movement → **Decreases**

→ More intense typhoons with slower northward movement in the warmer climate.

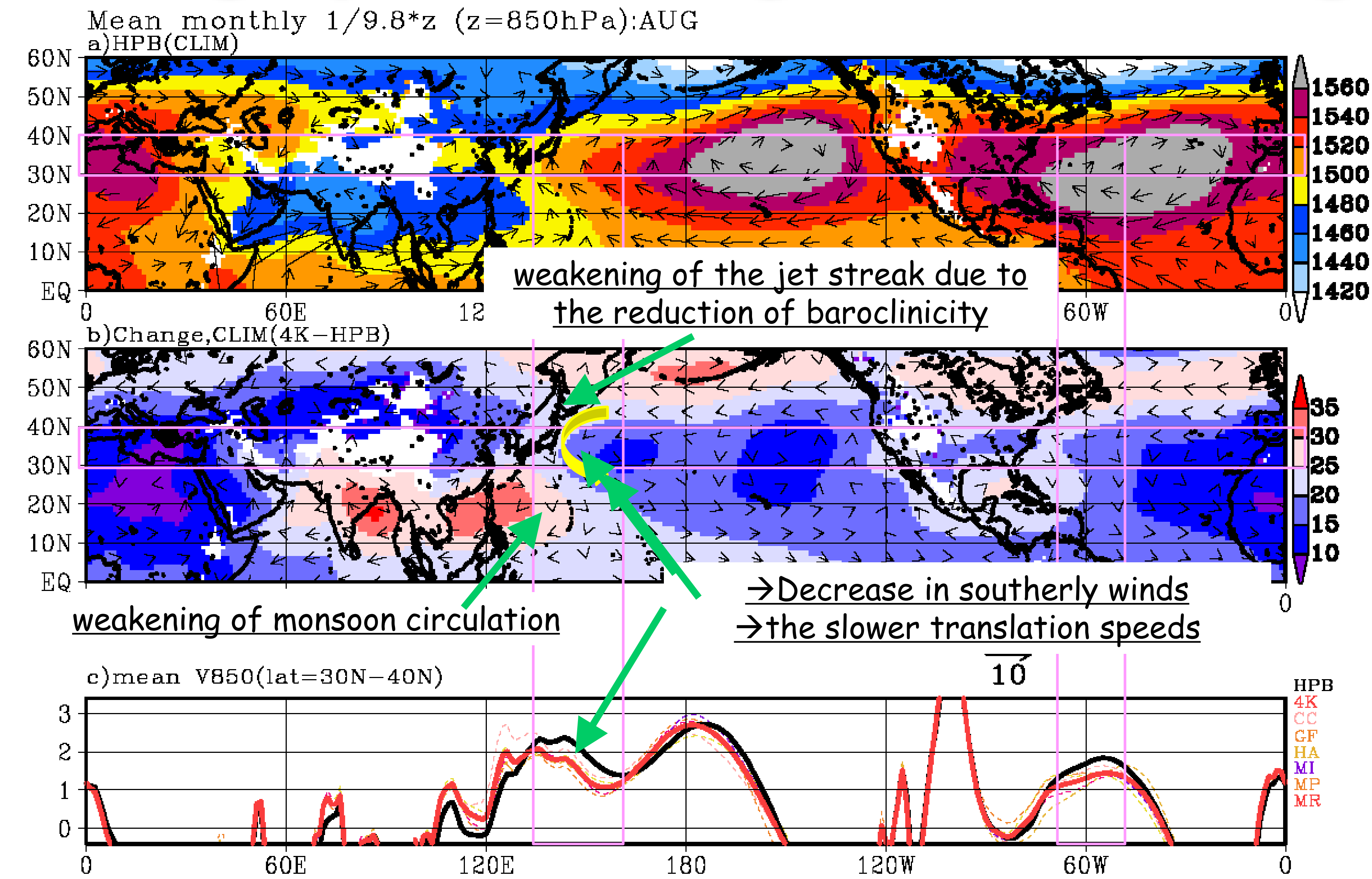
Mean geopotential height and wind: Aug.

Monthly mean geopotential height and winds (August).



Monthly mean geopotential height and winds when the targeted typhoons appeared.

Mean geopotential height and wind: Aug.



All 4K simulation sets show similar decrease in the southerly

Results (2): DDS experiments by CReSS04

Four sets of *AGCM60-experiments;*

- historical climate simulation:
  1951-2010, 50 members → **3,000 years**
- non-warming simulation: 1951-2010, 100 members
- +2K future climate simulation: 2031-2090, 54 members
- +4K future climate simulation:
  2051-2110, 90 members → **5,400 years**

DDS experiments by CReSS04

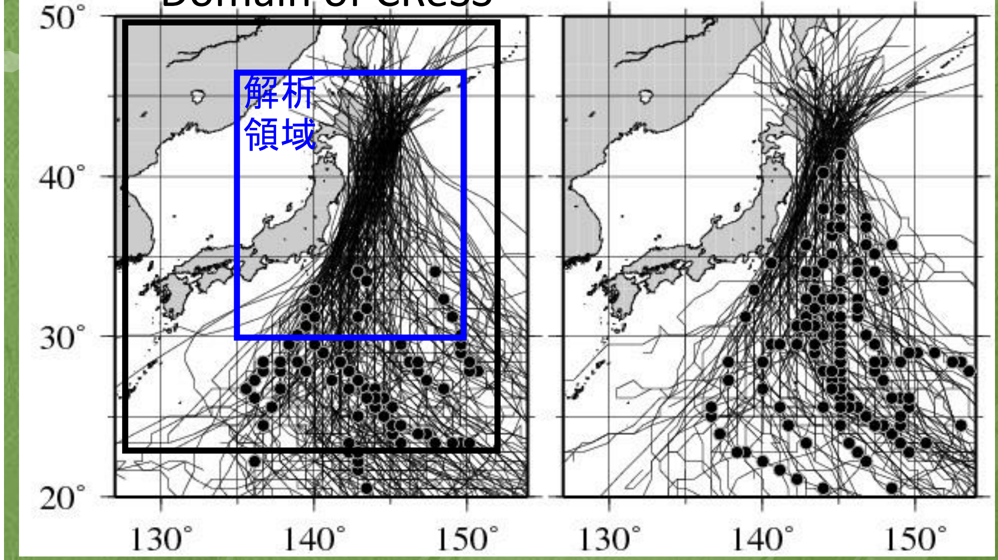
Table 3 Ensemble years and frequencies of the targeted typhoons.

	Ensemble years	Total frequencies
BT	67	8
HPB	3000	98
4K	5400	125

Table 4 Model descriptions

	Model descriptions
Model	Cloud Resolving Storm Simulator (CReSS) version 3.4
Horizontal resolution	0.04 deg. (Approximately **4km**)
Domain	See right figures
Cumulus parametrization	**None**
Cloud physics	Simple 2-moment 3-ice bulk
Boundary conditions	Every 6 hours from NHRCM20 in d4PDF
SST	**1D-slab ocean model**
Target	**All typhoons in Table 3!**

Domain of CReSS



Tracks of all typhoons simulated by CReSS04.

Changes in TY intensity

Table 5 Mean minimum central pressure (MCP30), the latitude of MCP30 (Latmcp30) in the analysis region.

	MCP (hPa)		LATmcp (度)	
	HPB	4K	HPB	4K
AGCM60	955	945**	34	35.4*
CReSS04	957	948**	35	34.5

**: 95% significant
*: 90% significant by t-test

In the 4K climate,

- Mean intensity → **Increase**
- Northward shift in Lat_{mcp} →Not clear in CReSS04

The maximum intensity :

CReSS04: 922hPa → 884hPa

HPB 4K

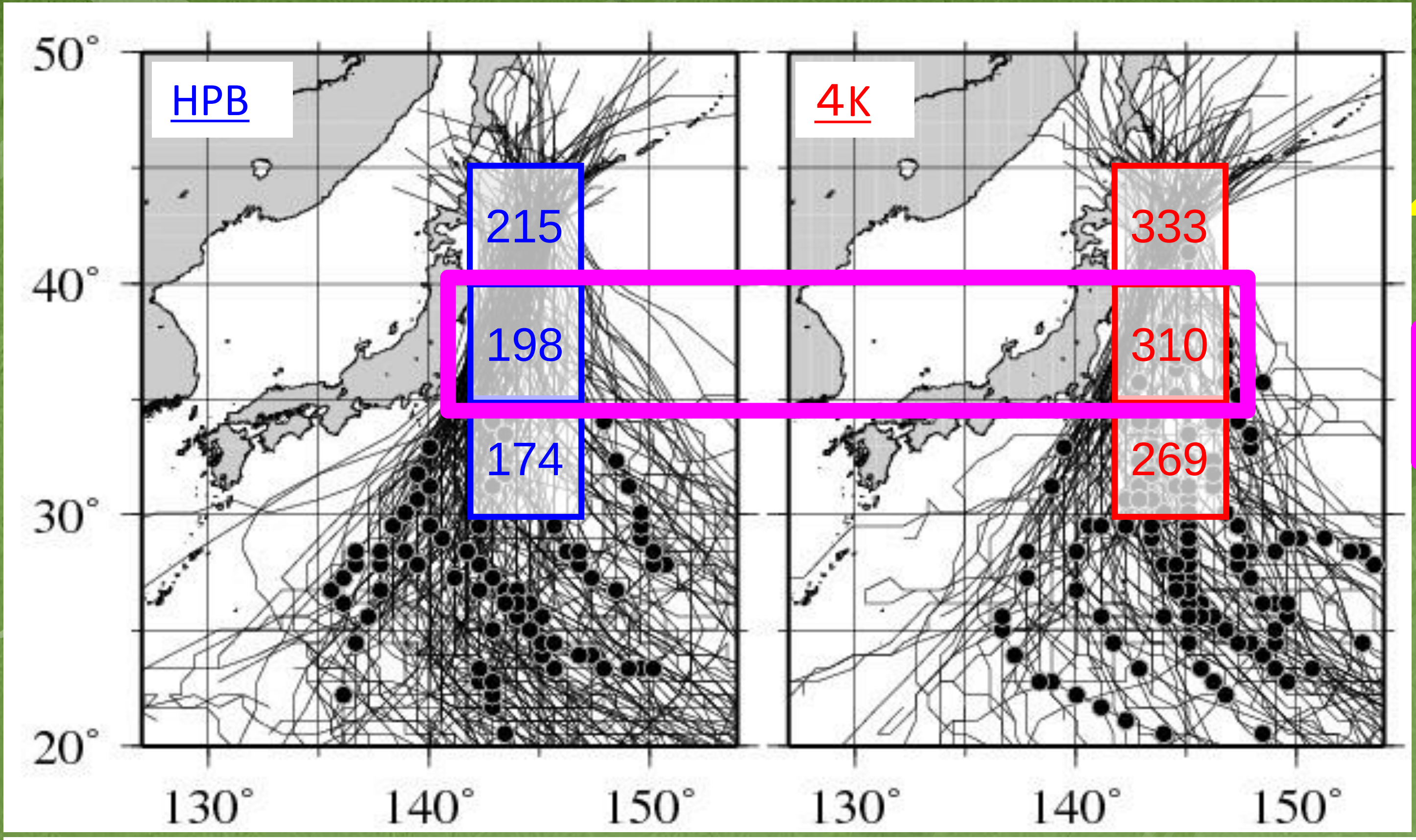
AGCM60: 915hPa → 901hPa

Obs: 925hPa (Songda, 2016; Oscar, 1995)

Changes in TY structures

Ty size
RMW
(km)

156*
136*
121



All typhoons whose centers were located in the boxes were composited.
(Total frequencies were shown in each box)

163*
120
119

Current typhoons become larger as traveling northward.

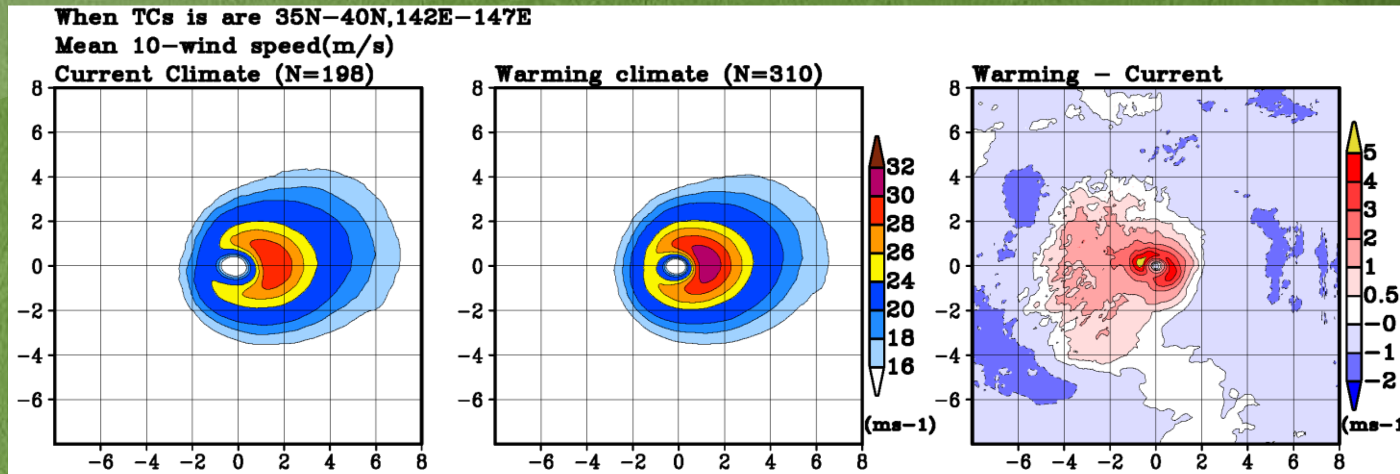
Extratropical transition

4K typhoons keeps compact structures.

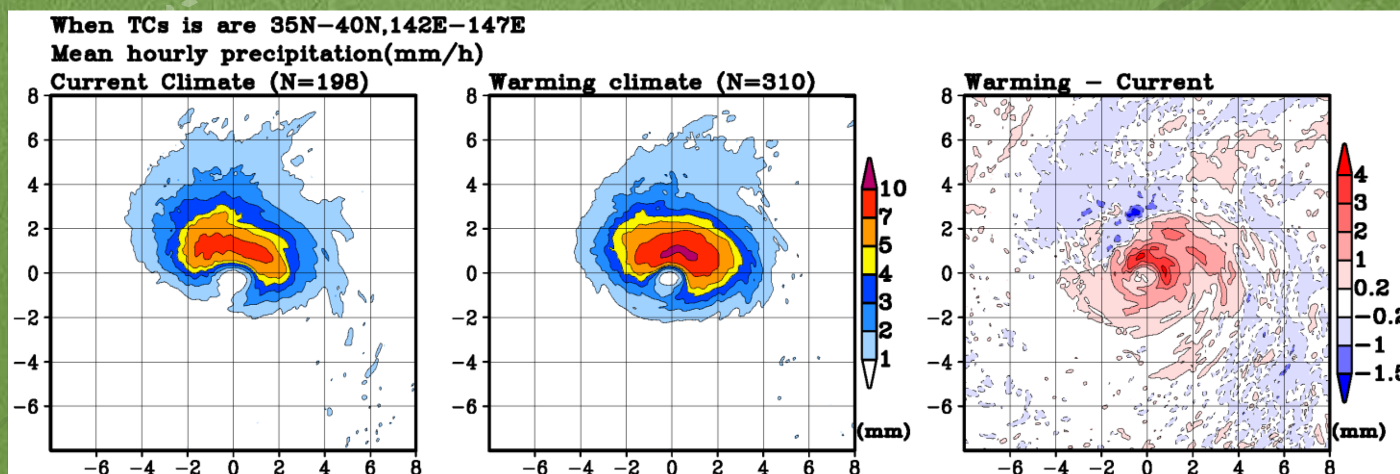
Center-composite horizontal structures (35N-40N,142E-147E)

HPB climate | 4K climate | Changes in 4K climate

10-m wind speed



Hourly Rain



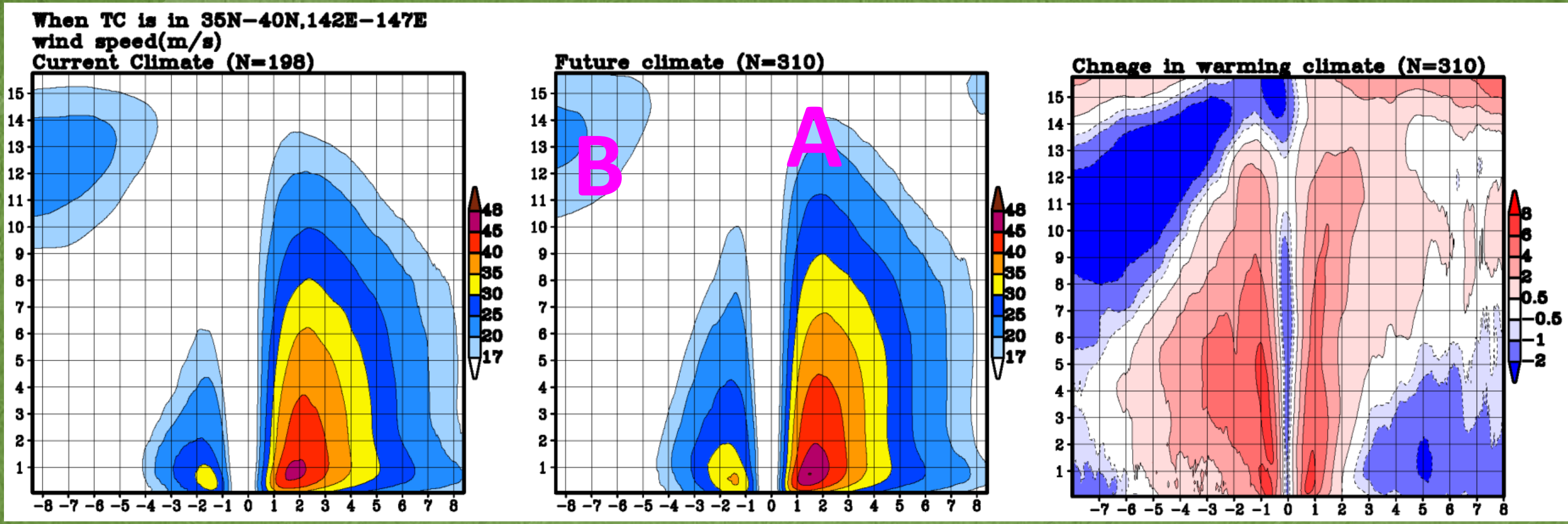
A compact typhoon with a smaller eye, but with more violent winds and intense precipitation around the storm center.

Center-composite vertical structures (35N-40N,142E-147E)

HPB climate

4K climate

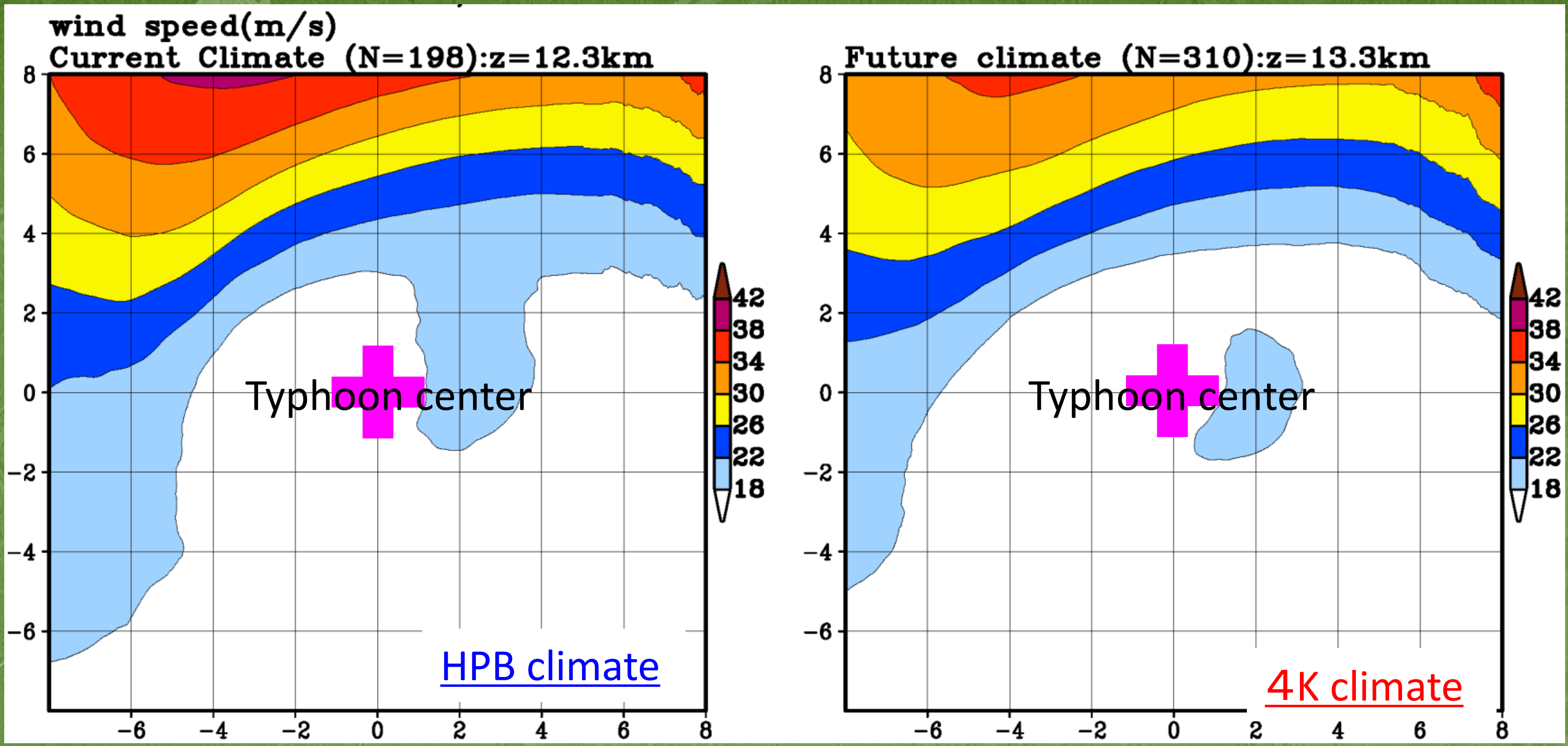
Changes in 4K climate



A compact typhoon with axisymmetric structures and intense circulation around the storm center. (A)

Weakening of the jet streak (B)

Upper-level jets in center-composite typhoons



In the 4K simulations, the upper-level jet closely related to the extratropical transition of tropical cyclones is weakening
→ The weakening of the upper-level jet allowed a typhoon to keep the axisymmetric tropical cyclone structures with intense winds and precipitation around the eye.

Summary

Current typhoons in the midlatitude

lose axisymmetric structures and expand strong wind regions as traveling northward

4K climate

Causes of extratropical transition of TCs :
Baroclinicity and low SST in midlatitude

- ✓ Reduction of baroclinicity（Ito et al. 2016）
- ✓ Increases in SST by 5℃（Mizuta at al. 2014）

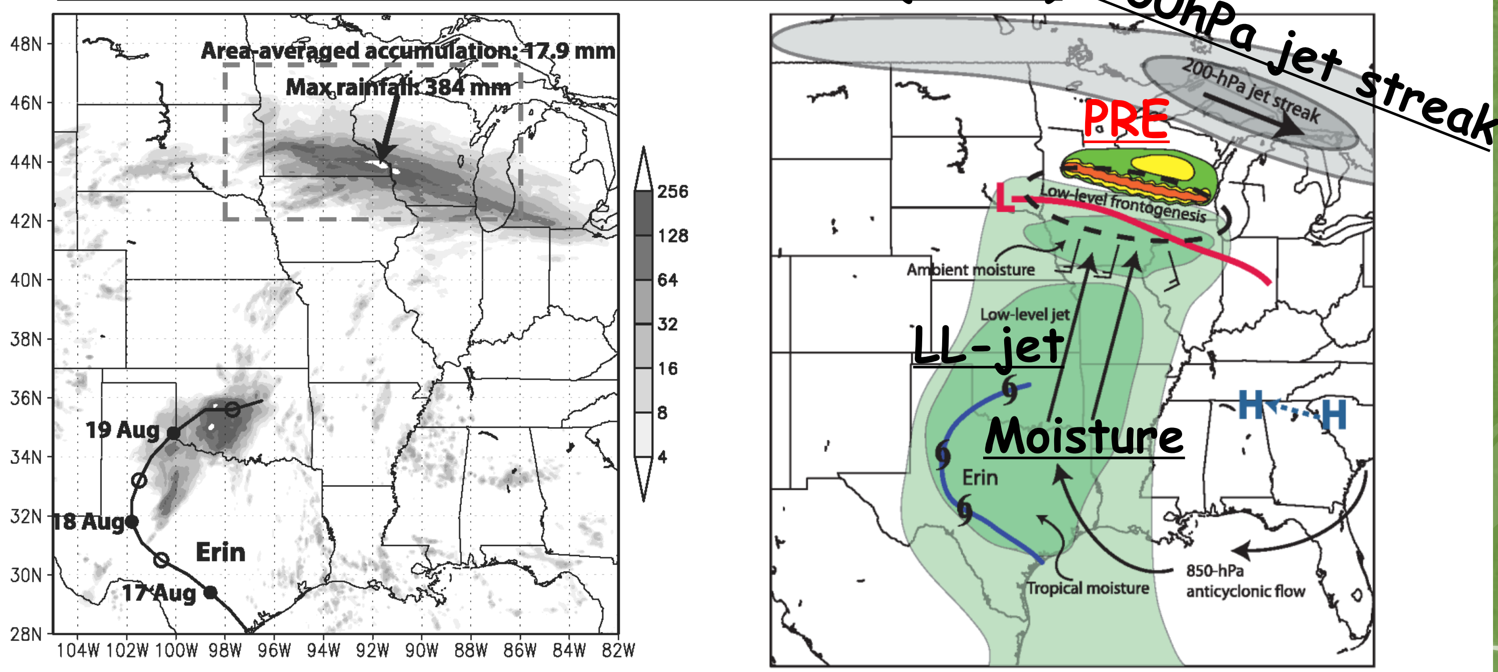
4K typhoon in the midlatitude

keeps compact and the axisymmetric tropical cyclone structures with intense winds and precipitation around the eye and travels northward in a slower translation speed

Remaining issues to be solved…

1. Analysis by the cyclone phase space
2. Changes in rainfall systems associated with the TCs (e.g. PRE)
3. Changes in characteristics of rainfall

PRE in North America: TS Erin (2007)



24-h rainfall (12Z18AUG-12Z182007): **384mm**

Schumacher et al. (2011)

Backup

①緯度帯別　台風の平均構造

**: HPB vs 4Kで99%以上有意
#: 緯度帯比較で99%以上有意

			30N-35N	35N-40N	40N-45N	
強さ	MWS m/s	HPB	35	34#	30#	←北上とともに衰弱
		4K	**40****	**36**** #	31#	←40Nまで有意に強
最大風速半径	RMW km	HPB	121	136#	156#	←北上とともに有意に拡大
		4K	119	**120****	163#	←40Nまで拡大せず
中心付近の平均風速と降水量	W200 m/s	HPB	24	24	19	中心付近の風雨、全緯度で有意に増加
		4K	**27****	**26****	**20***	
	P200 mm/h	HPB	4.3	3.9	2.8	
		4K	**6.7****	**5.4****	**3.7****	
ws<25m/sの面積	N25 km2	HPB	7194	8946#	6243	←北上とともにいったん拡大
		4K	**10267****	9543	6743	←拡大せず

温暖化気候下では、中心付近の風雨を強めた、より小さな目のコンパクトな台風に。

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(Deg.)	4K	34.8*	33.0	35.0	35.5
Vn					0.39
(Deg.					0.33**

**: 95

In the 4K climate,

- Mean intensity → **Increase**
- Northward shift in Lat_{mcp} →Not clear in CReSS04

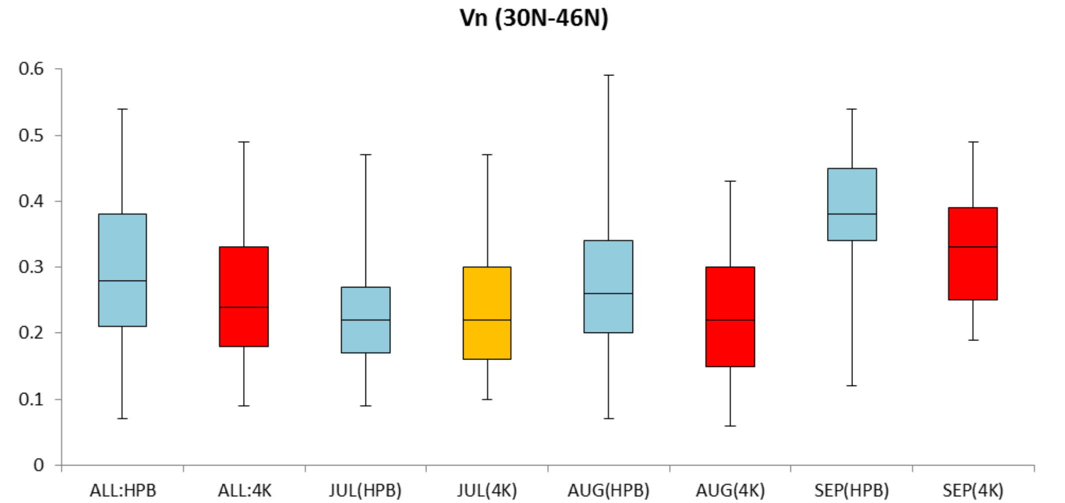

Fig. 2 Mean translation speeds of the targeted typhoons in the analysis region. Red boxes indicate that the difference in mean values was 99% statistically significant by two-sided t-test.