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Projection of Future Storm Surges around the Korean Peninsula based on Large Ensemble Climate Experiments

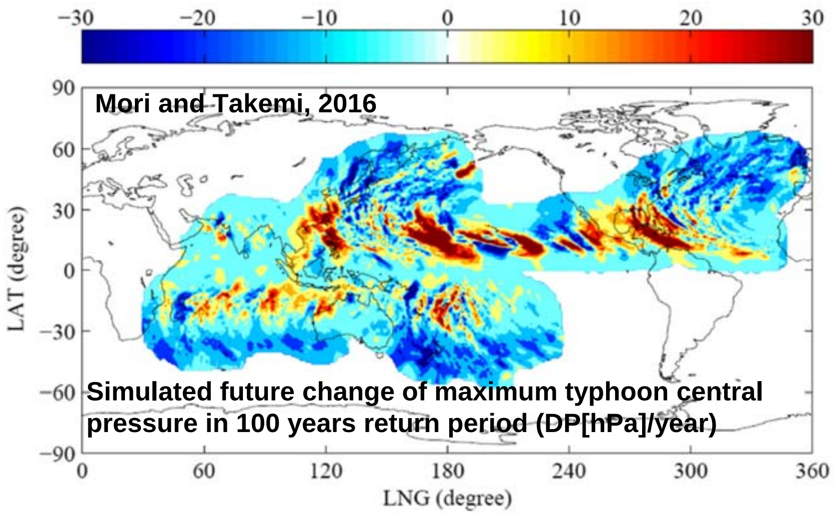
Jung-A Yang, Nobuhito Mori,
Sooyoul Kim and Hajime Mase

KOREA UNIVERSITY 1905
DPRI-KU
鳥取大学 Tottori University

BACKGROUND – impact of global climate change

It is expected

- global climate change leads to more severe TC (IPCC AR4, 2007; Emanuel, 2005; Webster et al., 2005; Elsner et al., 2008; Woodruff et al., 2013).



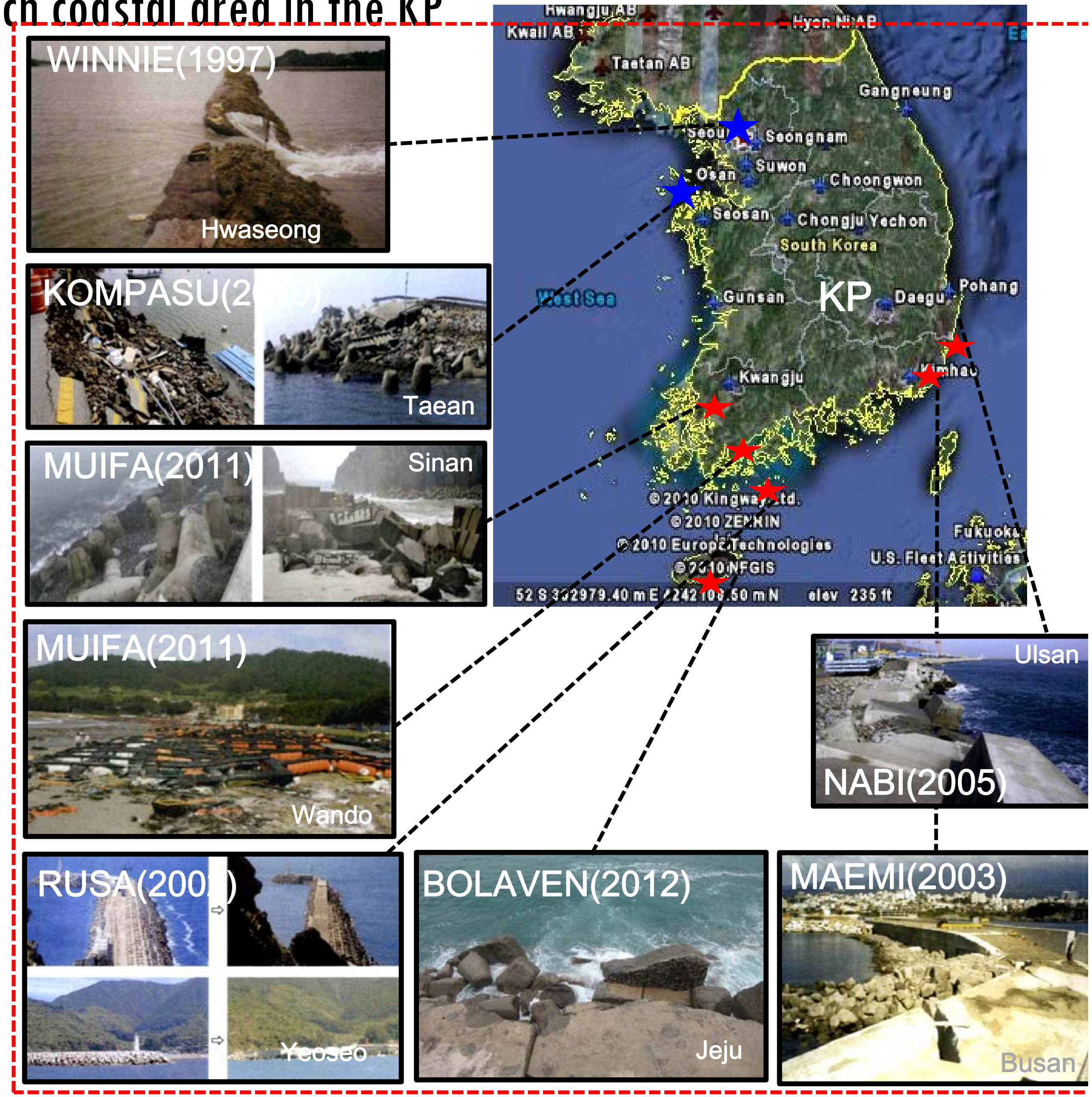
- future storm surge heights (hereafter, SSHs) and other coastal disaster aspects will be changed depending on oceans and regions.

- Long-term assessment of TC-induced storm surge at regional scales under projected climates is one of the important factors in coastal risk reduction (Lin et al., 2012; Mori and Takemi, 2016).

BACKGROUND – the Korean Peninsula (KP)

- Topographic characteristics of each coastal area in the KP
  - the East coast : strong flow by s
  - the West coast : large tidal vari
  - the South coast : complex coast
- Geographical characteristics of t
  - Located in the pathways of typh
  - An average of three typhoons ev
    from 1959 to 2015 affects the KP

⇒ The western and southern coasts of the KP actually suffered from storm surge-induced disaster several times in the past.



BACKGROUND – the Korean Peninsula (KP)

- Topographic characteristics of each coastal area in the KP
  - the East coast ： strong flow by seasonal wind
  - the West coast ： large tidal variation
  - the South coast ： complex coastal topography

- Geographical characteristics of the KP
  - Located in the pathways of typhoons
  - An average of three typhoons every year from 1904 to 2015 affects the KP (NTC,2016)

- In view of the climate change effects, it is expected …
  - Regional sea level rise around the will be higher than the global average (IPCC AR4, 2007)
  - Total number of TC affecting the northwest Pacific region will decrease
  - Frequency of TC with very high intensity will increase (Mori and Takemi, 2016)

These factors raise concern about increased storm surge disasters in the KP.

OBJECTIVE AND CONTENTS OF RESEARCH

- To project future storm surges around the Korean peninsula based on large ensemble climate simulations

To estimate reproducibility and uncertainty of typhoon data from ensemble climate simulations by comparison with observed typhoon data

↓

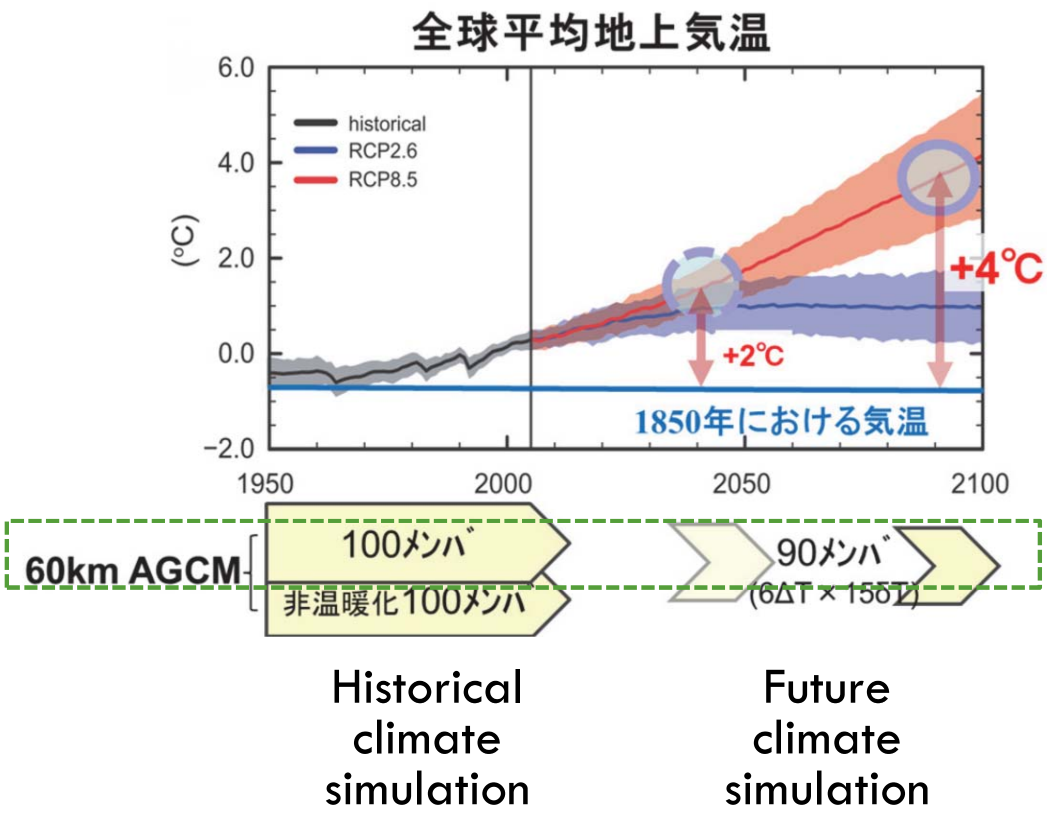
To discuss future changes of typhoon properties such as track, genesis number and intensity

↓

To assess SSHs with particular return period, 100-year and 500-year, on regional scale

METHODOLOGY

- Unprecedentedly large ensemble experiments of climate simulation using MRI-AGCM3.2H (Mizuta et al., 2016) : d4PDF
  - d4PDF : Database for Policy Decision-Making for Future Climate Change
  - Probabilistic future changes in extreme events with low-frequency on local scales can be estimated directly without application of statistical models

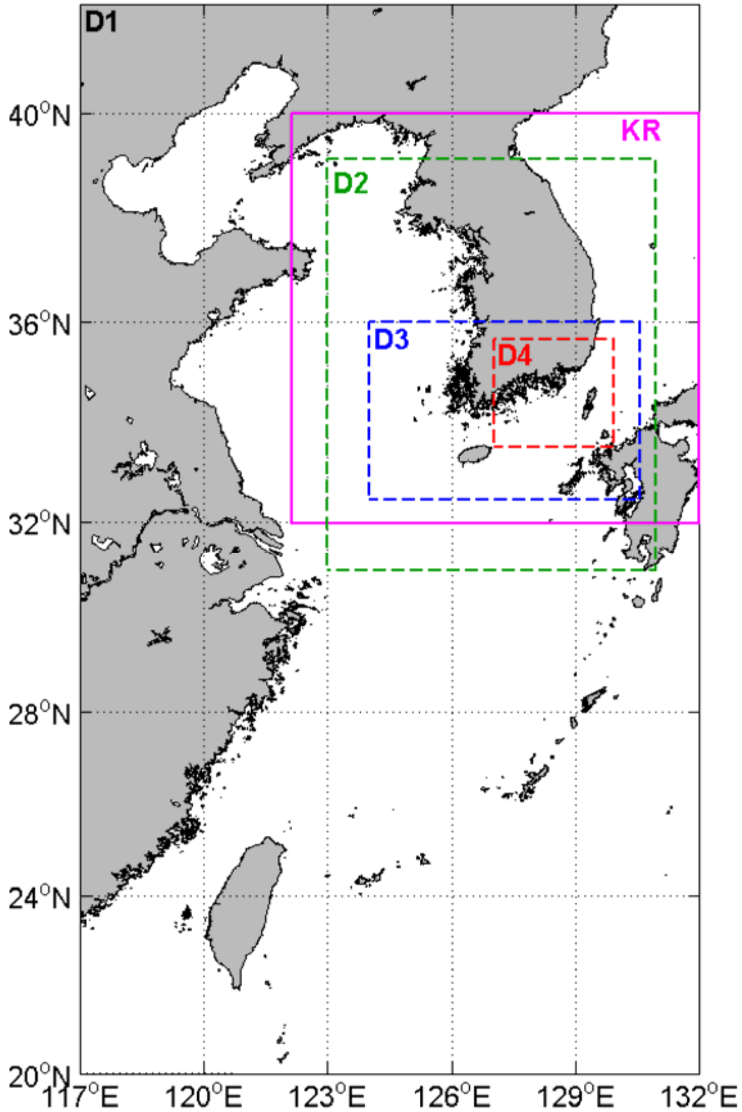


- Historical and future climate experiments were used
- Each experiment was abbreviated to d4PDF_{past} and d4PDF_{future}

(Figure from http://www.miroc-gcm.jp/~pub/d4PDF/design_en.html)

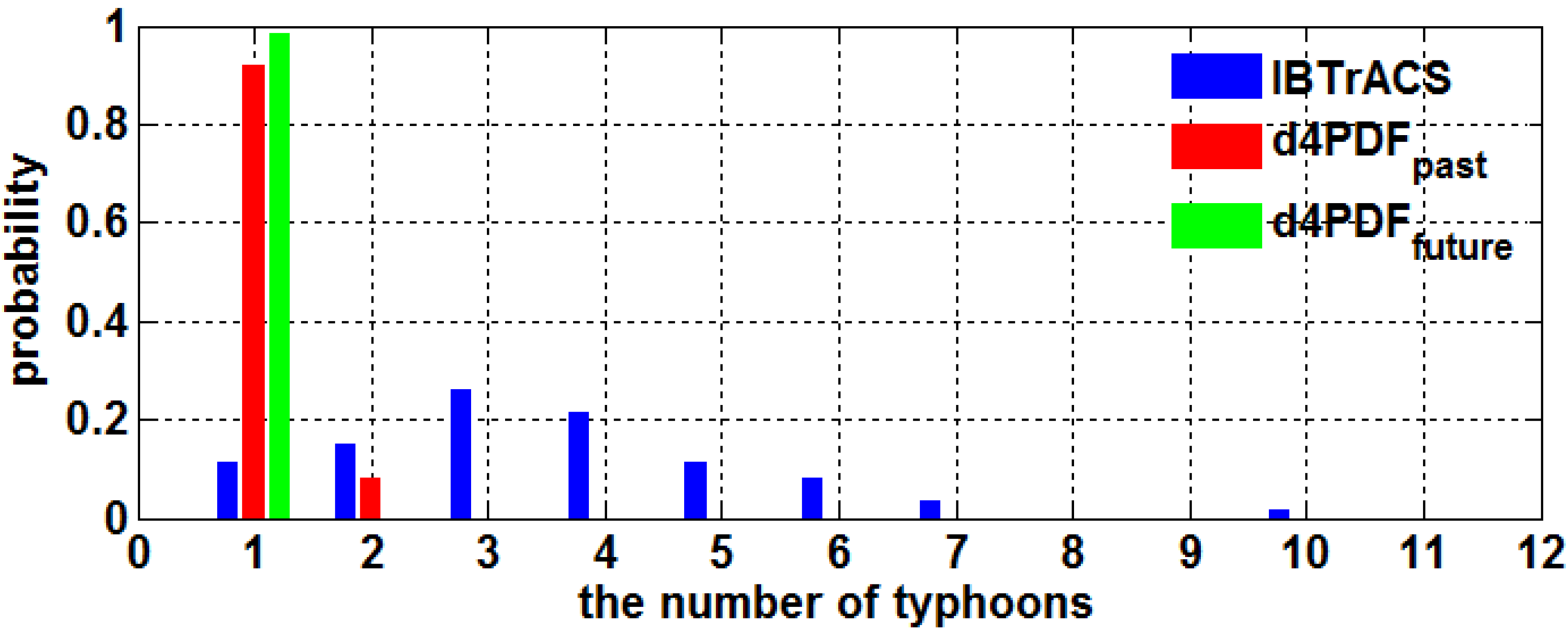
METHODOLOGY

- Typhoons affecting the Korean Peninsula (hereafter, typhoons around KP)
  - Focus on typhoons which pass through the region of 32°-40°N and 122°-132°E
  - Typhoon properties : the number, track, minimum central pressure
  - Verification by comparing with observed typhoon dataset from the International Best Track Archive for Climate Stewardship (IBTrACS; Knapp et al., 2010)
  - Assessment of its future change by comparing typhoon data of d4PDF$_{past}$ with d4PDF$_{future}$
- TC detention method (Murakami et al., 2012)
  - Considerations : relative vorticity, wind speed, temperature, duration of storm



REPRODUCIBILITY AND FUTURE CHANGE OF THE TYPHOON DATA

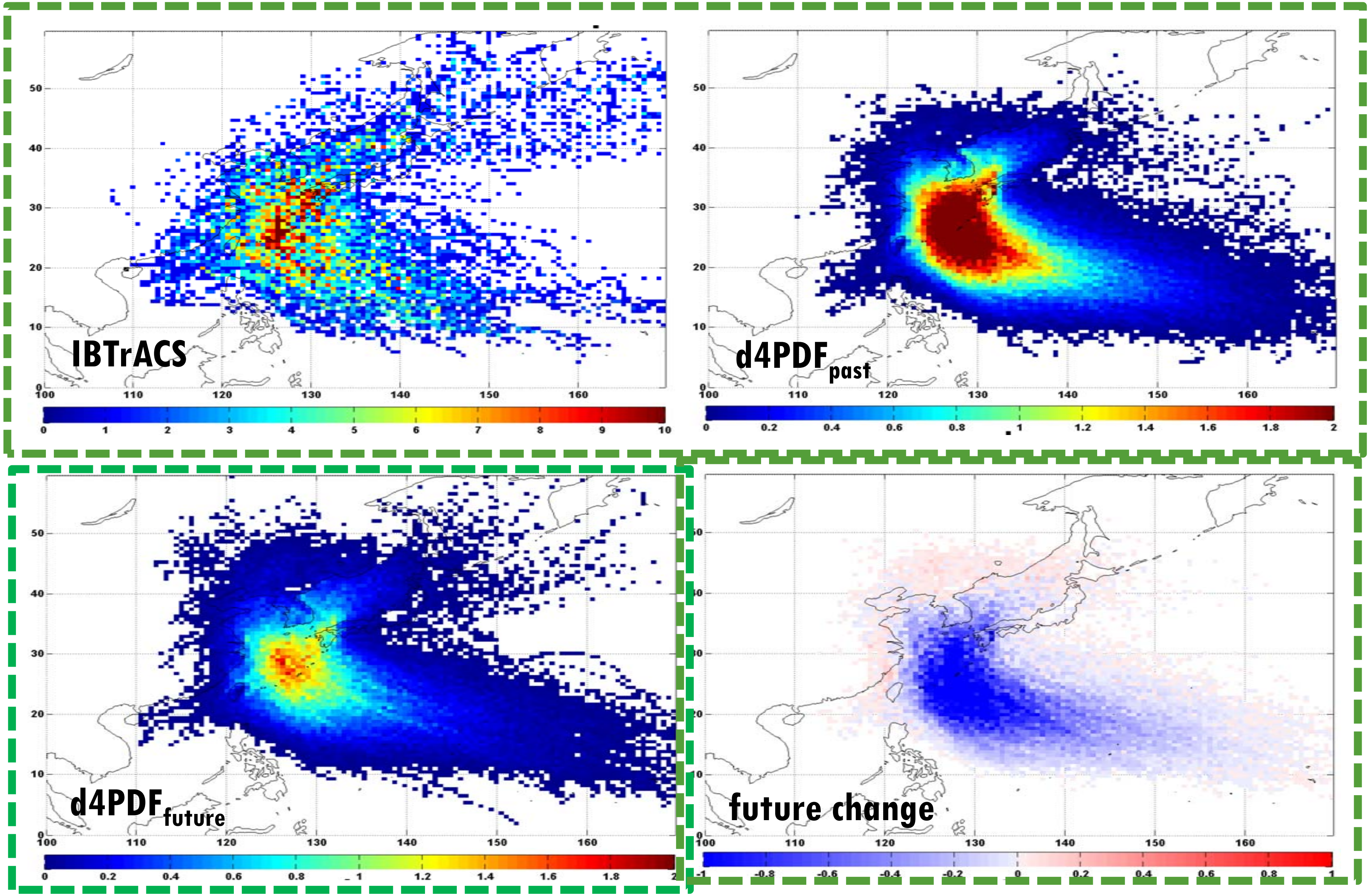
- Probability of annual number of typhoons passing around the KP



Climate Condition	Abbreviation	The number of typhoons	Yearly average number of typhoons	Future decreasing rate of the yearly average number of typhoons [%]
Present	Observation	214	3.6	-
	$d4PDF_{past}$	6,475	1.1	-
Future	$d4PDF_{futre}$	3,632	0.7	36

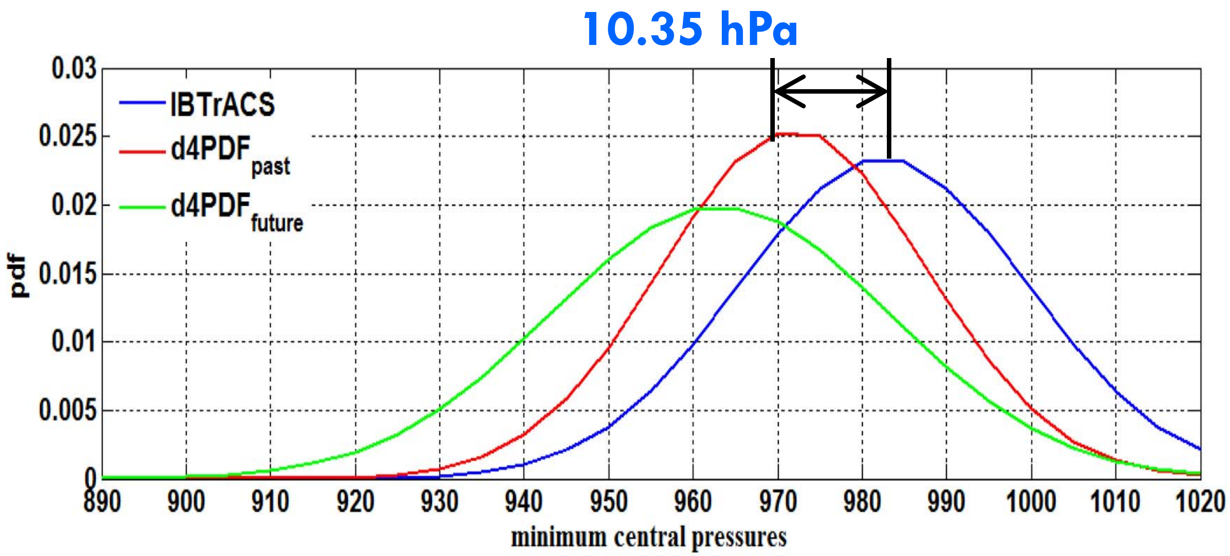
REPRODUCIBILITY AND FUTURE CHANGE OF THE TYPHOON DATA

- Tracks based on annual number of typhoons affecting the KP passing through each grid

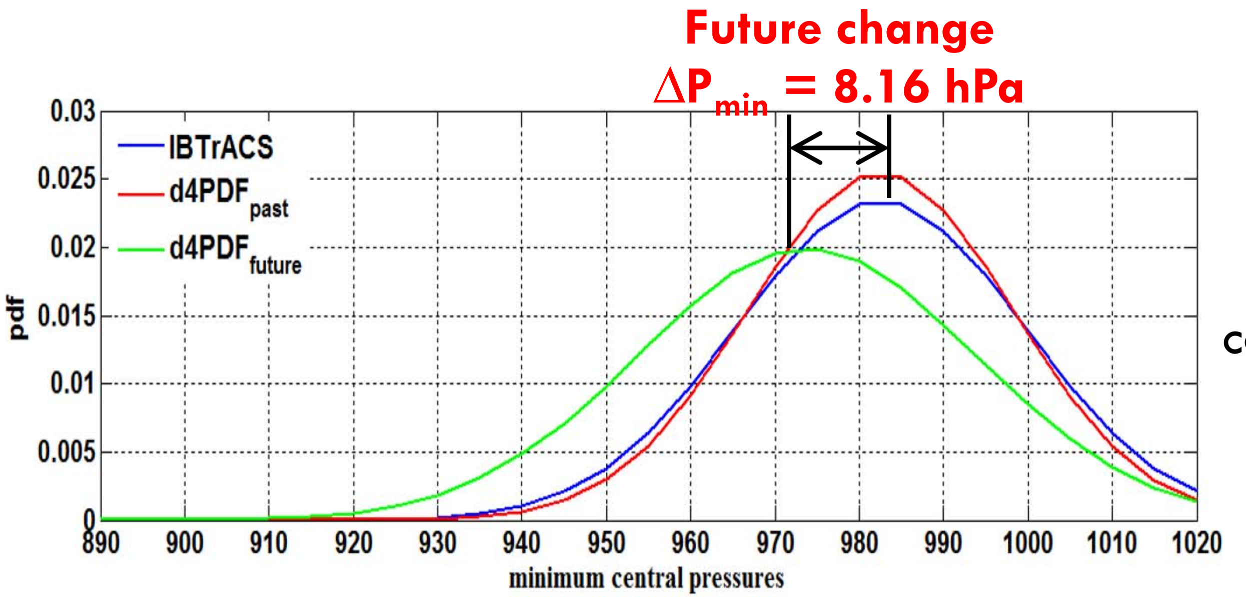


REPRODUCIBILITY AND FUTURE CHANGE OF THE TYPHOON DATA

- Probability and quantile-quantile plot of minimum central pressure



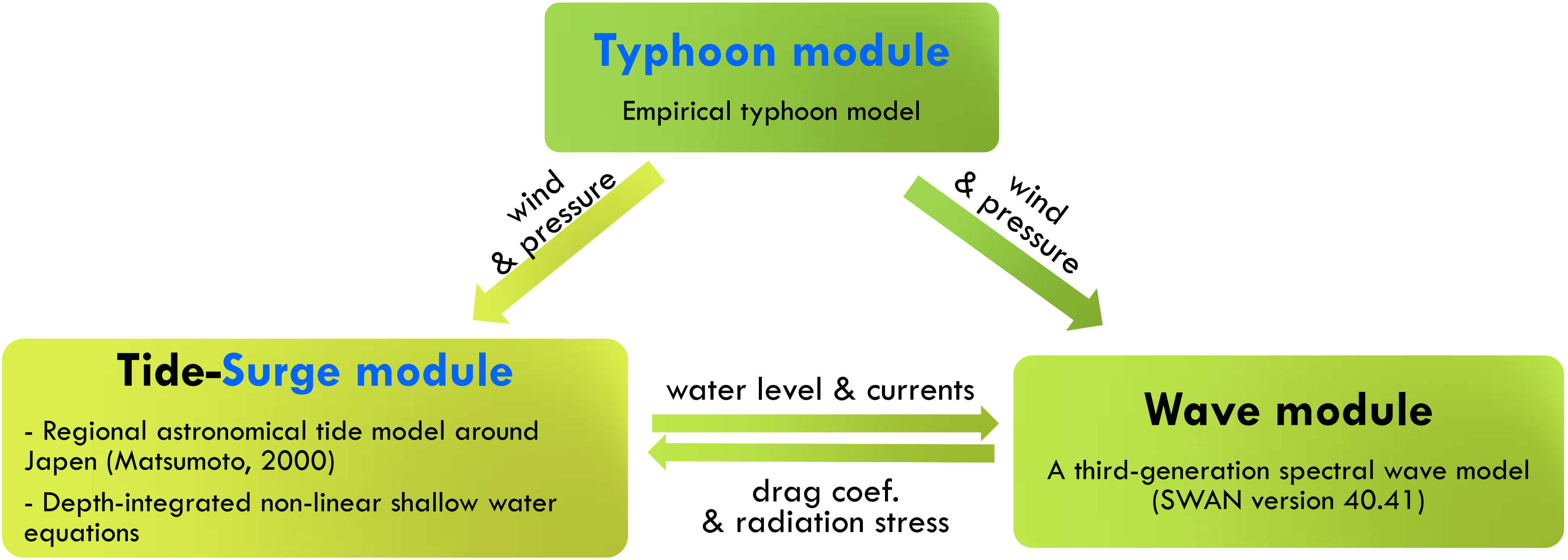
before correction



after correction

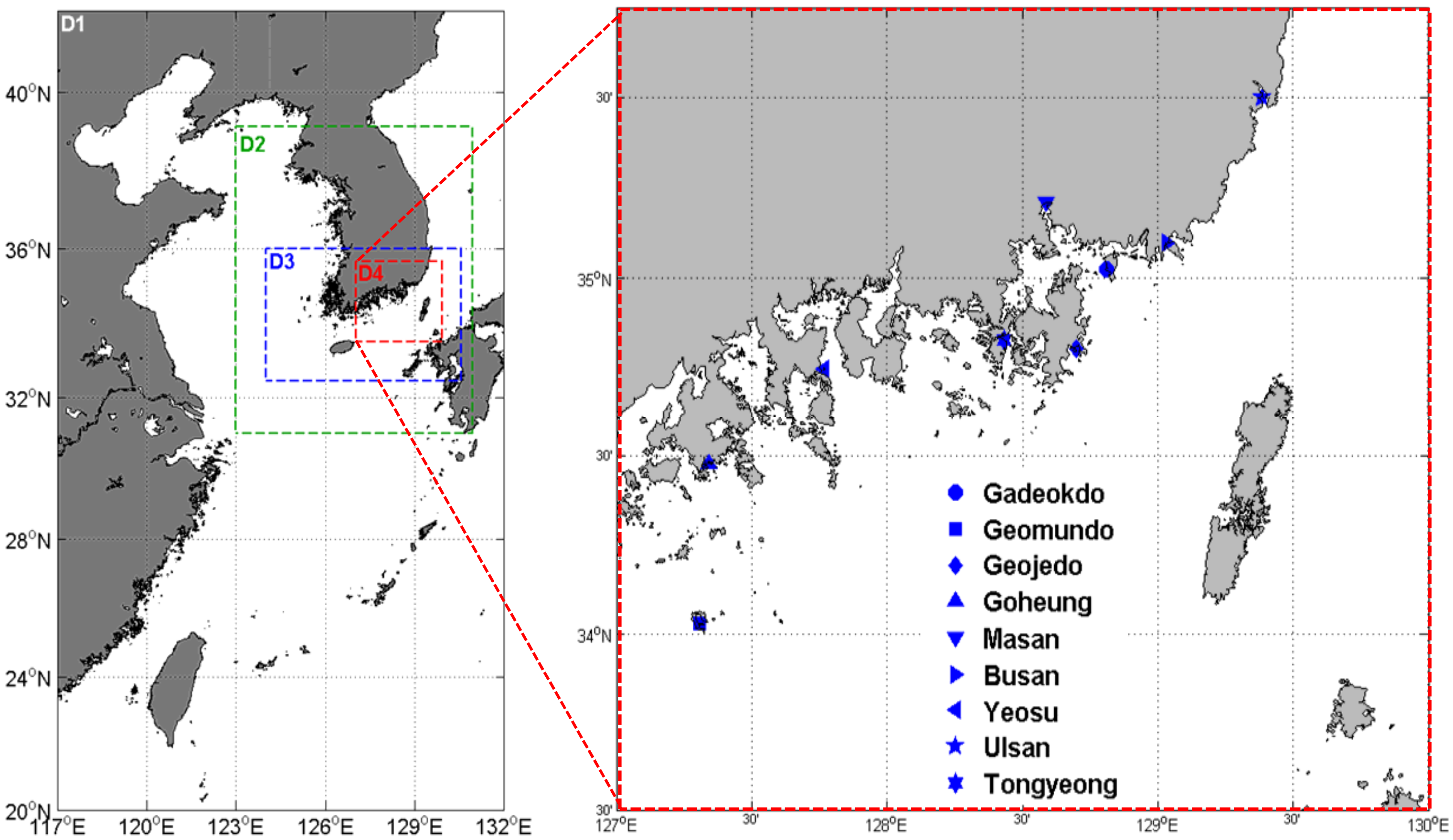
NUMERICAL MODEL AND MODEL SETUP

- A coupled surge, wave and tide model (SuWAT; Kim *et al.*, 2008)



- Model setup
  - Empirical typhoon model : Fujita model for pressure and the Mitsuyasu-Fujii for wind distributions
  - Typhoon parameters: Digital Typhoon Data Base (2014), except Rmax which is given by an observed empirical formula (Yasuda et al., 2010)

SIMULATION CONDITIONS



- nesting with a 1:3 ratio
- spin-up : 48 hours
- Calculation time step : 300 sec
- bathymetry data
  - GEBCO (2003) for D1
  - KorBathy30s (Seo,2008) for remaining domains

D#	The range of domain	The grid size	# of grids
1	117°E ~ 132°, 20°N ~ 42°N	Δx = 9,059.8m, Δy = 11,560.5 m	151 X 211
2	123°E ~ 131°, 31°N ~ 39°N	Δx = 4,563.2m, Δy = 5,547.1m	160 X 160
3	124°E ~ 130.5°, 32.5°N ~ 36°N	Δx = 2,281.8m, Δy = 2,773.2m	260 X 140
4	127°E ~ 130°, 33.5°N ~ 35.75°N	Δx = 760.7m, Δy = 924.5 m	360 X 270

SIMULATION CASE AND ESTIMATION METHOD FOR SSHS WITH R-YEAR RETURN PERIOD

- Case for simulation of future SSHs

# of typhoon	IBTrACS :1951-2011	$d4PDF_{past}$:1951-2011	$d4PDF_{future}$: 2051-2110
total	-	515,206	295,655
typhoons affecting the KP	214	6,475	3,632
(after correction of P_{min}) $P_{min} \leqq 970hPa$	-	1,428	1,522

- Formula for estimation of SSHs with R-year return period (Goda, 1988)

$$R = \frac{1}{\lambda(1-P)}$$

- *R* : a return period
- λ : an average annual incidence rate
- *P* : a cumulative probability which is associated m[th] smallest value of the maximum SSHs data and estimated using plotting position formula

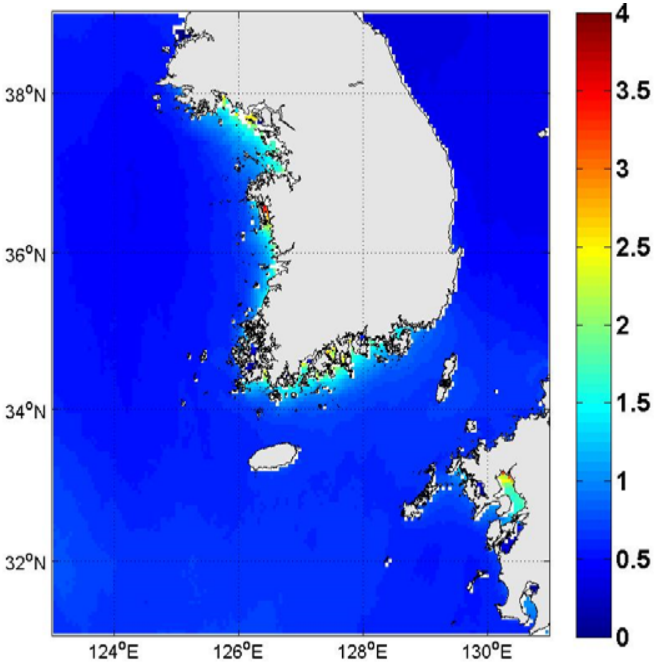
Plotting position formula (Weibull, 1939)

$$P = \frac{m}{N+1}$$

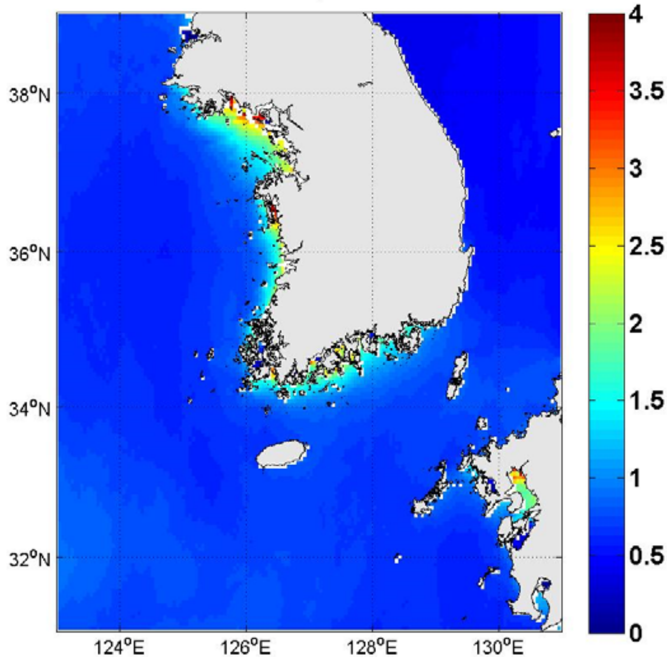
- M : the rank of the value of the maximum SSHs which has a value of 1 for the largest value
- N : the total number of the maximum SSHs

SPATIAL DISTRIBUTIONS OF SSH_S ALONG THE KP (D2)

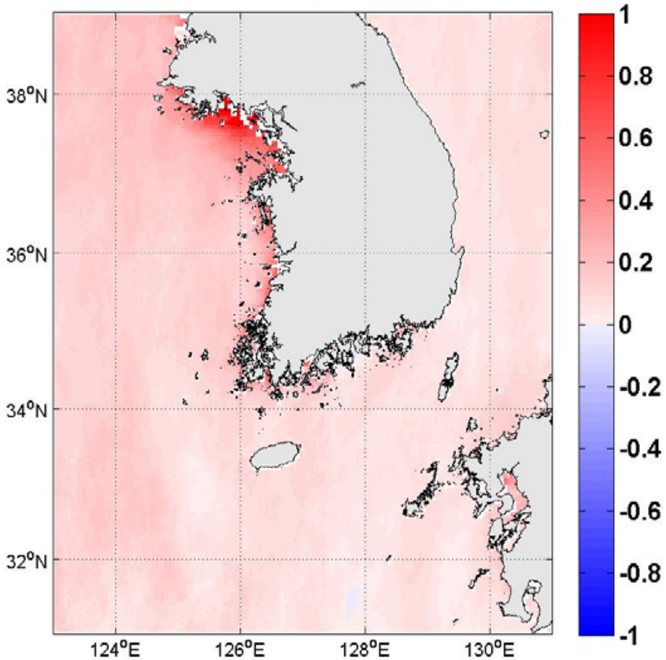
- with 100-year return period (unit : m)



(a) past climate



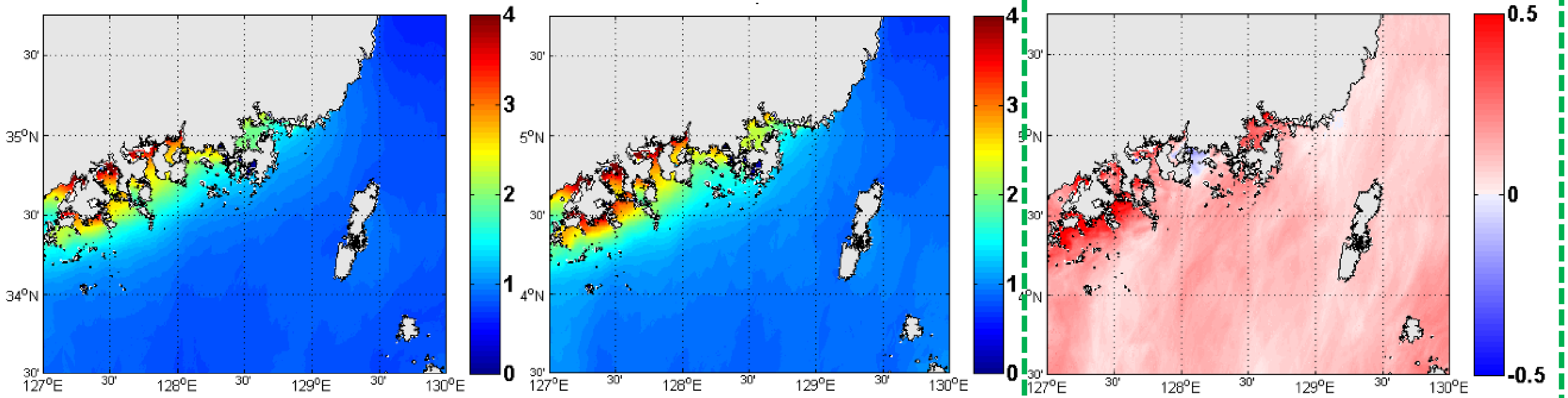
(b) future climate



(c) future change

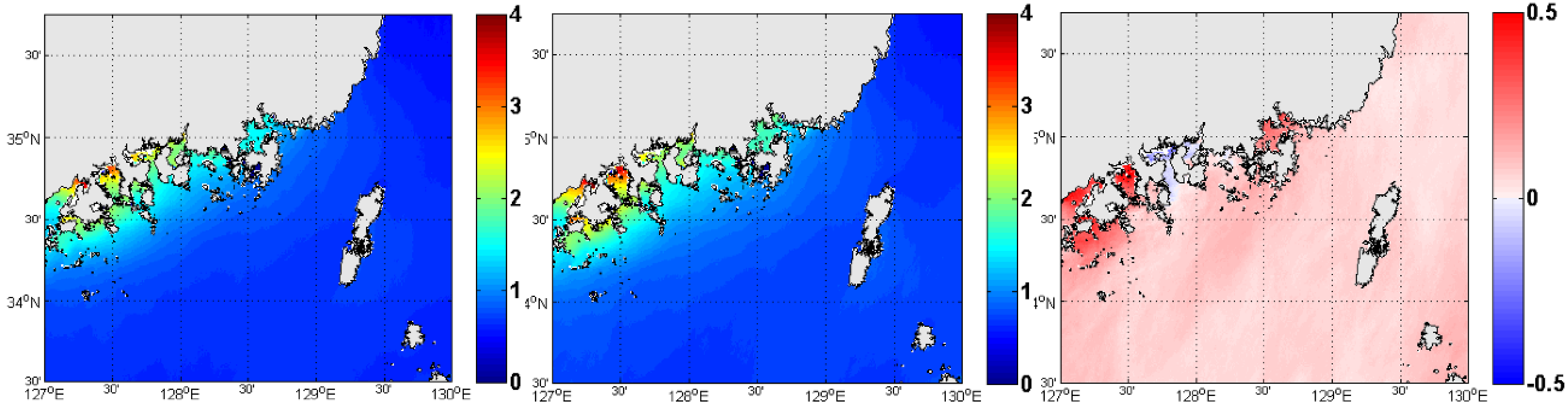
SPATIAL DISTRIBUTIONS OF SSHs ON THE SOUTHEASTERN AREA OF THE KP (D4)

- with 100-year return period (unit : m)



(a) past climate (b) future climate (c) future change

- with 500-year return period (unit : m)



(a) past climate (b) future climate (c) future change

SUMMARY

- Reproducibility of the typhoon data under present climate
  - The yearly average number of typhoons around KP is underestimated comparing to the observations
  - The general trend of the tracks of them corresponds with the observations
  - The mean value of the minimum central pressure is smaller than observations by 10.35 hPa
- Future changes of typhoons properties
  - The number of the typhoons around KP is expected to decrease by 38%
  - Significant future change of the minimum central pressure is evident when intense typhoons whose pressures are smaller than 940 hPa
  - The locations of typhoon genesis and typhoon lysis are projected to shift to the northwest
- Future changes of maximum SSH with 100-year return period
  - The locations of the vulnerable area to storm surge shift to the north area of the western region and to the west area of the southern regions in the KP under the future climate.
  - The magnitude of future change of SSH vary spatially. The maximum variation was estimated to 0.61 m (15.4%) with 100-year return period in the west area of the southeastern coast of the KP