

# Future Projections of Global Wave Climate by Multi-SST and Multi-Physics Ensemble Experiments

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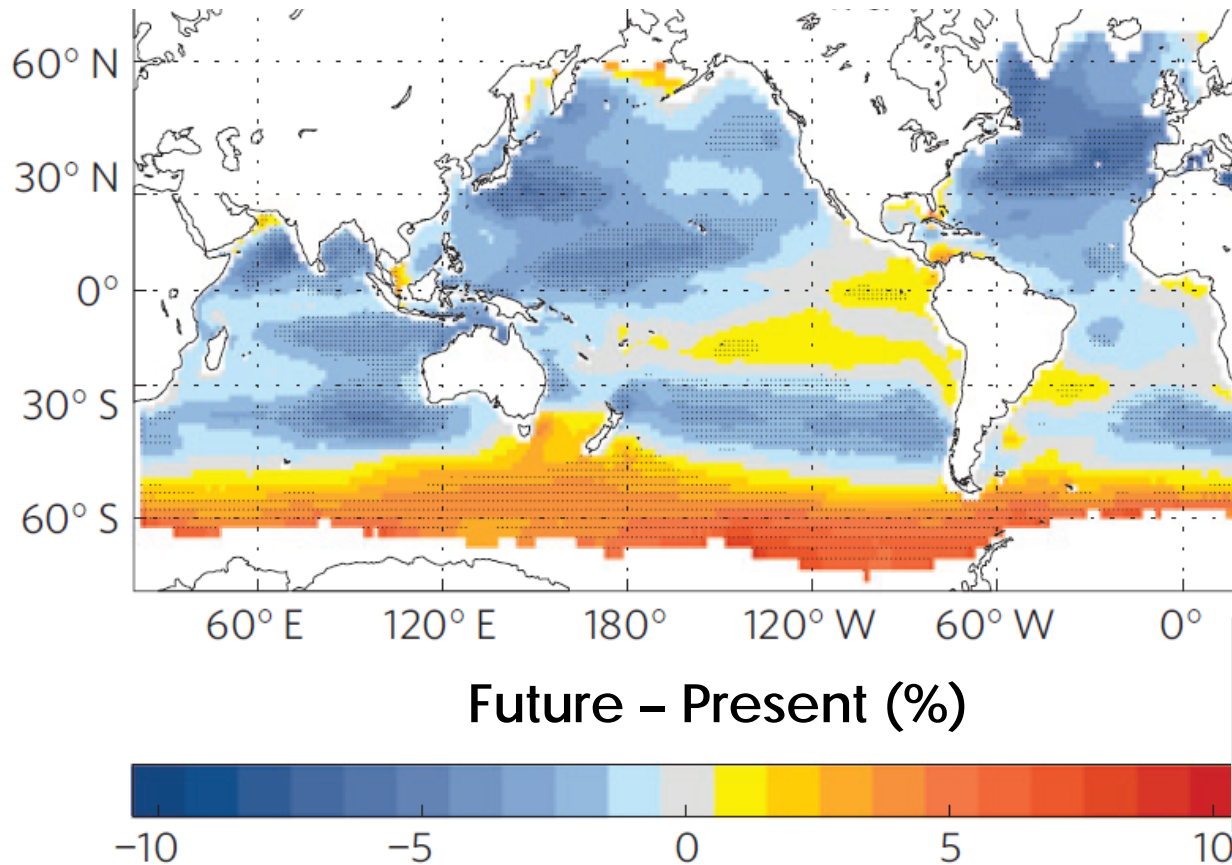
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# Future Projection of Global Wave Climate

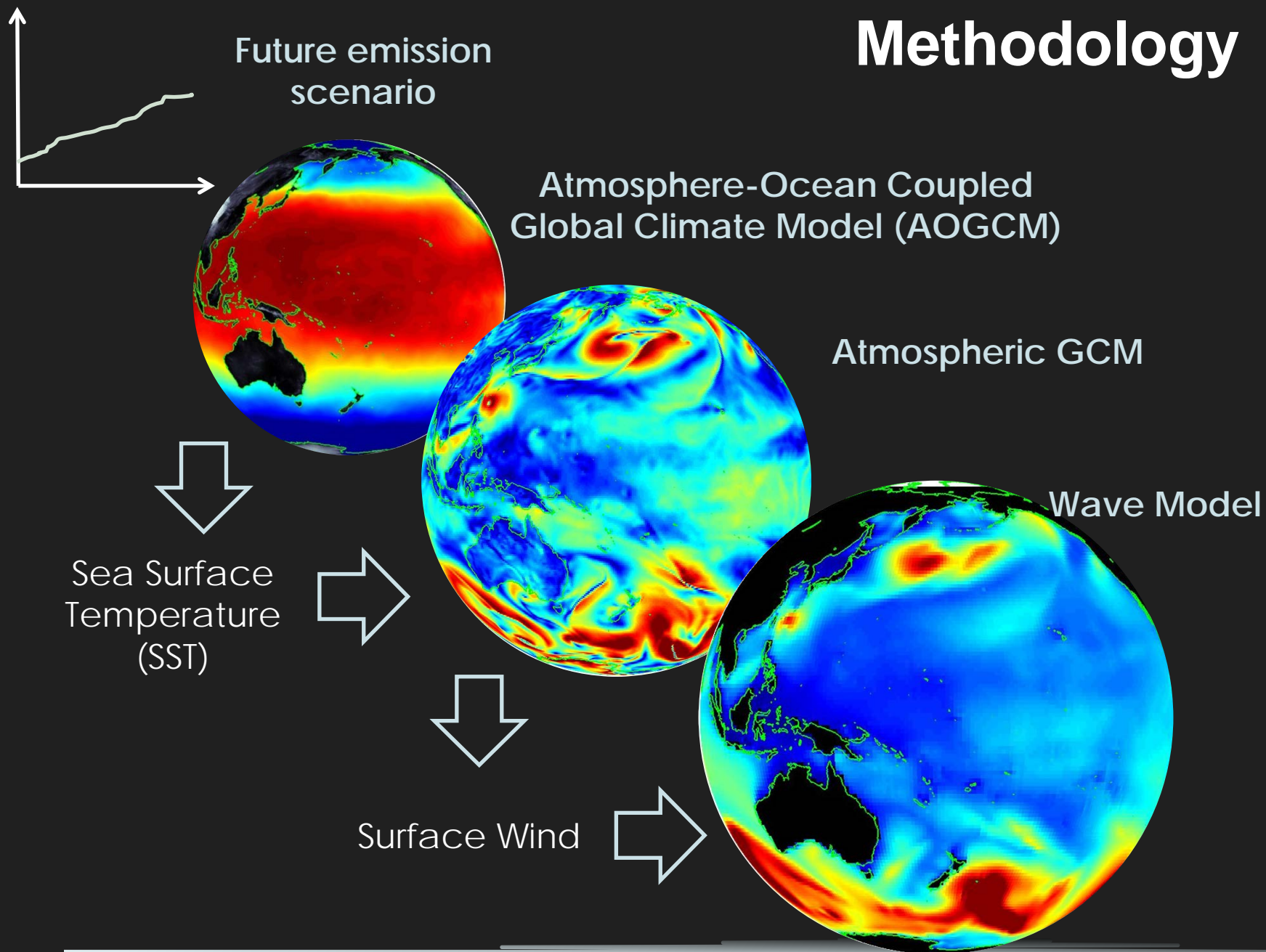
Ensemble projection of future change in mean significant wave heights from 5 studies (20 members).



Wang and Swail (2006)  
Mori et al. (2010)  
Hemer et al. (2012)  
Fan et al. (2013)  
Semedo et al. (2013)

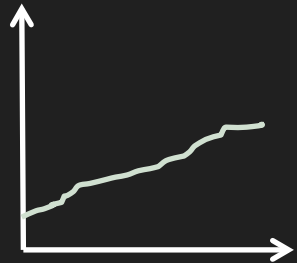
M. Hemer et al. (2013, *Nature Climate Change*) :  
Projected changes in wave climate from a multi-model ensemble

# Methodology

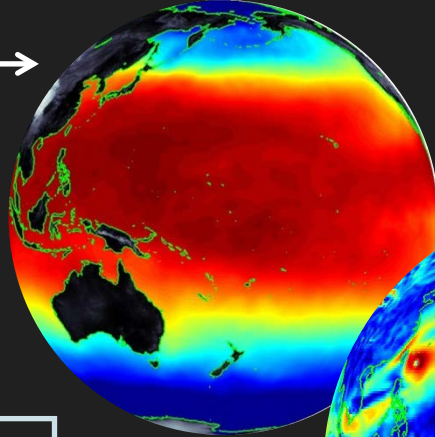


# Methodology

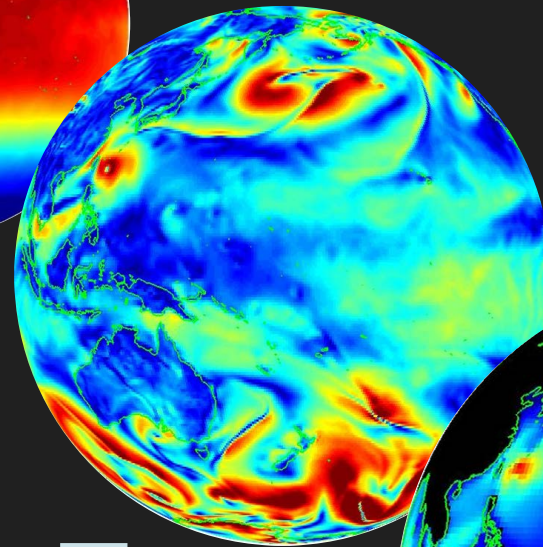
Future emission scenario



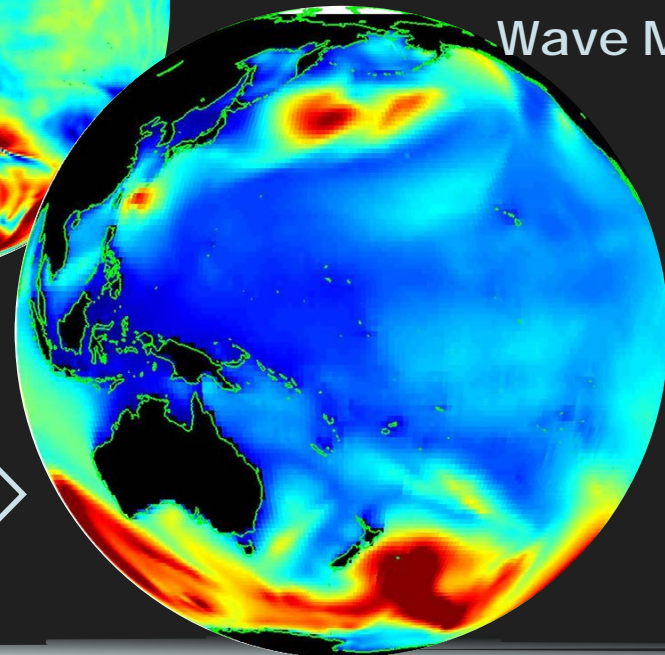
Atmosphere-Ocean Coupled Global Climate Model (AOGCM)



Atmospheric GCM



Wave Model



Sea Surface Temperature (SST)

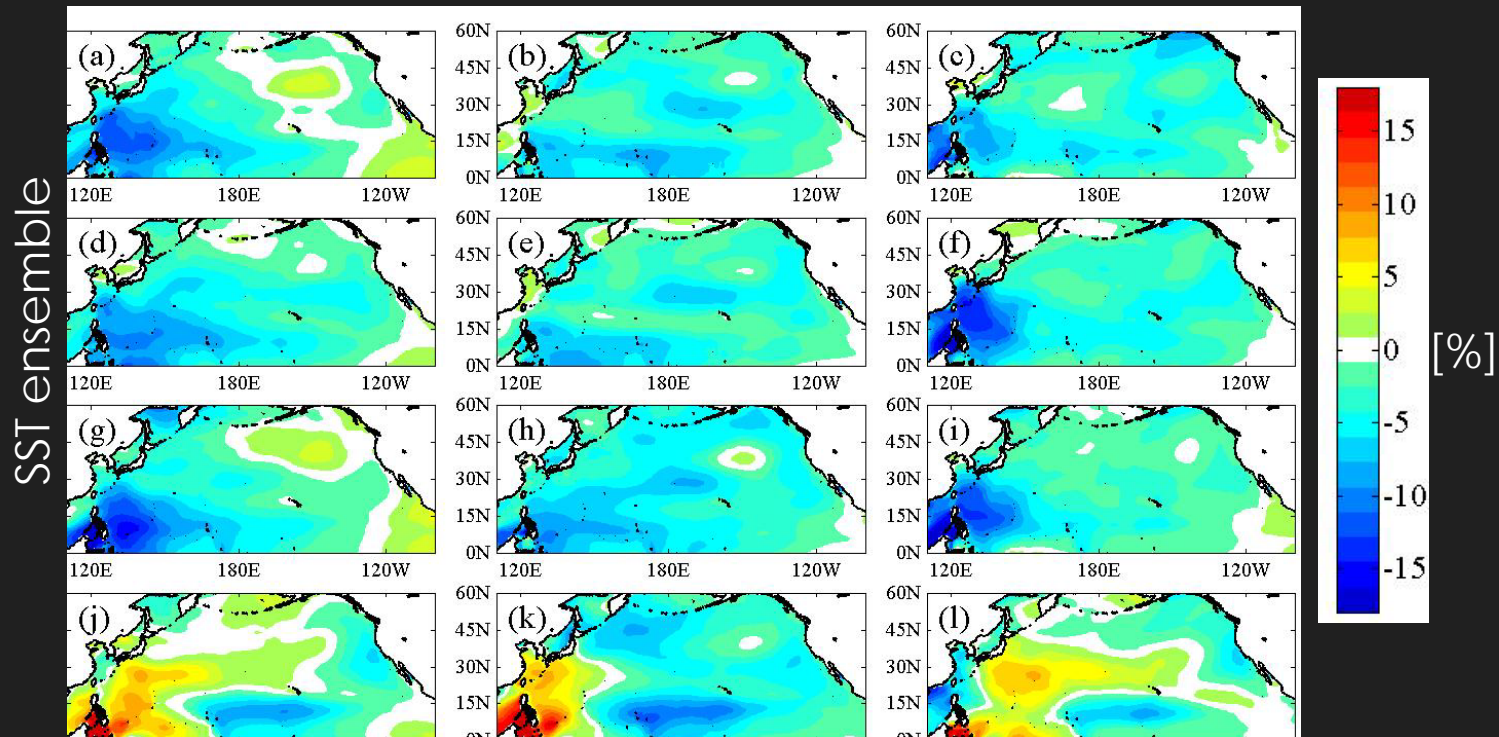


4 future SST conditions  
times 3PPE = 12 ensembles

Surface Wind

# Main finding

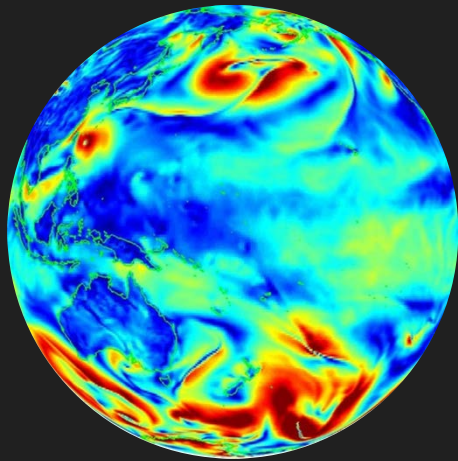
Future changes in MSWH in summer (JJASON) at the North Pacific  
Perturbed Physics ensemble



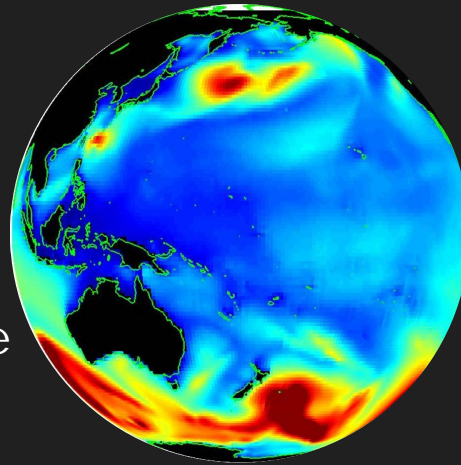
- **Variation of SST is major uncertainty source** of summertime wave climate in NP
- There is the robust relationship between future change pattern of SST and summertime wave climate
  - Relative growth of mean wave height under so-called cluster3 SST condition through change in **typhoon characteristics**.
- The results are consistent with COWCLIP studies

# Outline of Model

# Model description



Surface  
Wind



## Atmospheric GCM

MRI-AGCM3.2H

Spatial resolution

60km

SST

HadISST1, Cluster 0, 1, 2, 3

Cumulus convection scheme

Yoshimura (YS)

Arakawa-Schubert (AS)

Kain-Fritsch (KF)

## Global wave model

Wave Watch III

Spatial resolution

1°

Directional resol.

15°

Frequency band

0.04 – 0.5 Hz

Present Climate (1979-2009)

Physics SST \	YS	AS	KF
HadISST1	HPA_YS	HPA_AS	HPA_KF

Future Climate (2075-2099)

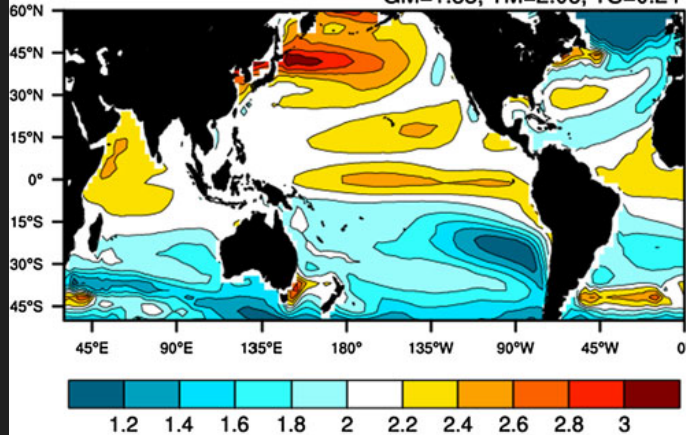
Physics SST \	YS	AS	KF
<b>c0</b>	HFA_YS_c0	HFA_AS_c0	HFA_KF_c0
<b>c1</b>	HFA_YS_c1	HFA_AS_c1	HFA_KF_c1
<b>c2</b>	HFA_YS_c2	HFA_AS_c2	HFA_KF_c2
<b>c3</b>	HFA_YS_c3	HFA_AS_c3	HFA_KF_c3

# 4 future SST conditions

## Future – Present (Murakami et al., 2012)

(a) CMIP3 Mean SST

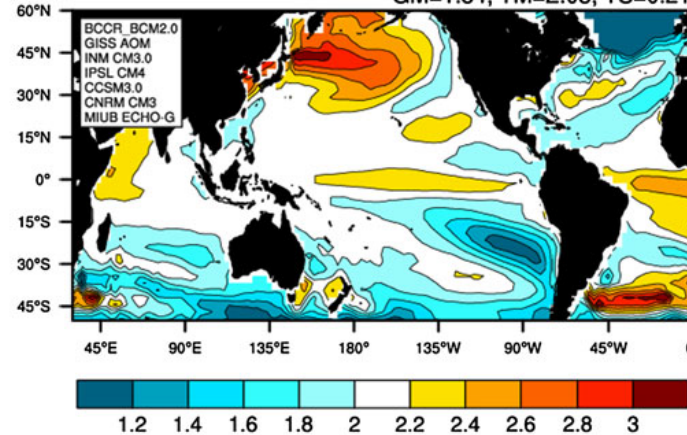
GM=1.83, TM=2.06, TS=0.24



**C0**  
(CMIP3  
mean)

(b) Cluster1 SST

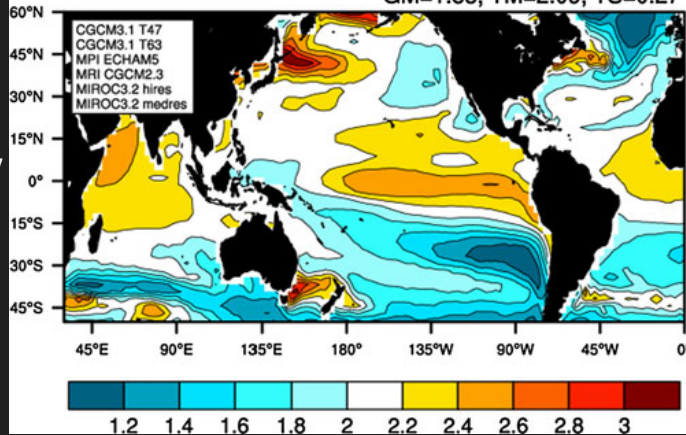
GM=1.84, TM=2.05, TS=0.21



**C1**  
(BCCR BCM2.0  
GISS AOM  
INM CM3.0  
IPSL CM4  
CCSM3.0  
CNRM CM3  
MIUB ECHO-G)

(c) Cluster2 SST

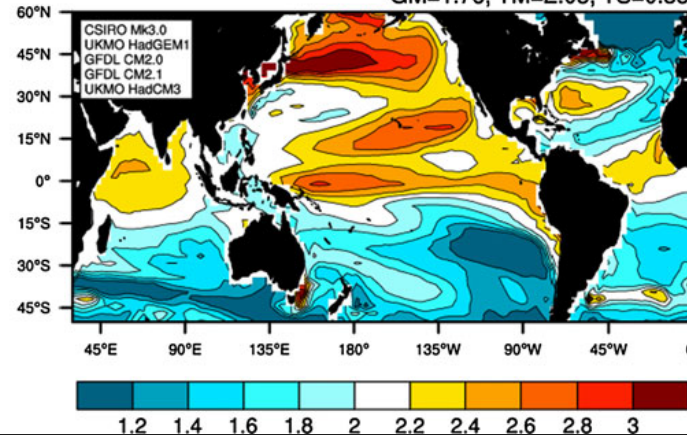
GM=1.85, TM=2.09, TS=0.27



**C2**  
(CGCM3.1 T47  
CGCM3.1 T63  
MPI ECHAM5  
MRI CGCM2.3  
MIROC3.2h  
MIROC3.2m)

(d) Cluster3 SST

GM=1.76, TM=2.05, TS=0.38



**C3**  
(CSIRO Mk3.0  
UKMO HadGEM1  
GFDL CM2.0  
GFDL CM2.1  
UKMO HadCM3)

C0 : Mean of 18 CMIP3 models (A1B scenario)

C1 – 3 : Clustered SST of 18 CMIP3

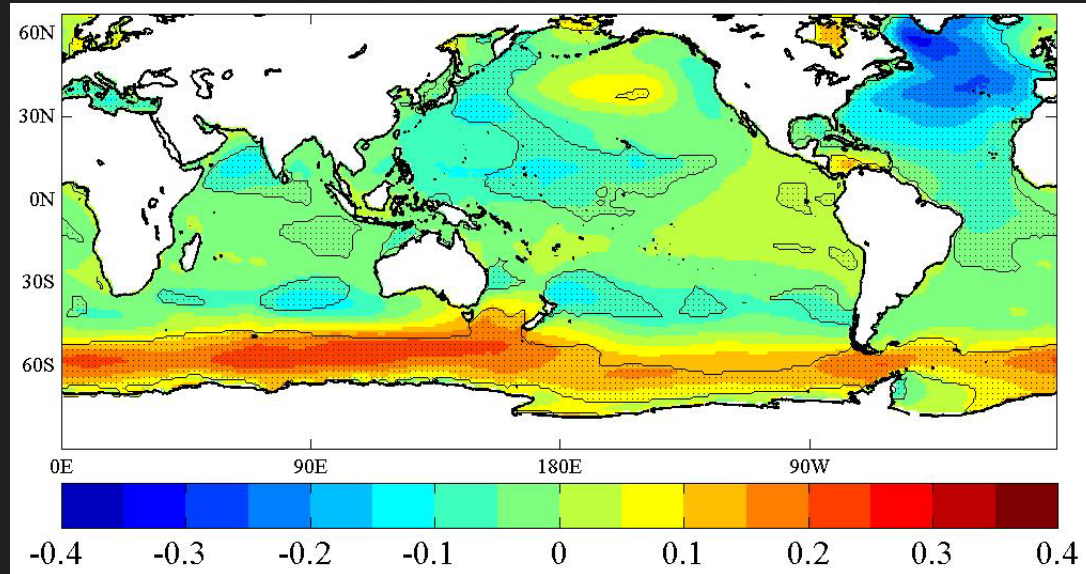
# Future Projections

Results

Mean Significant Wave Height (MSWH)

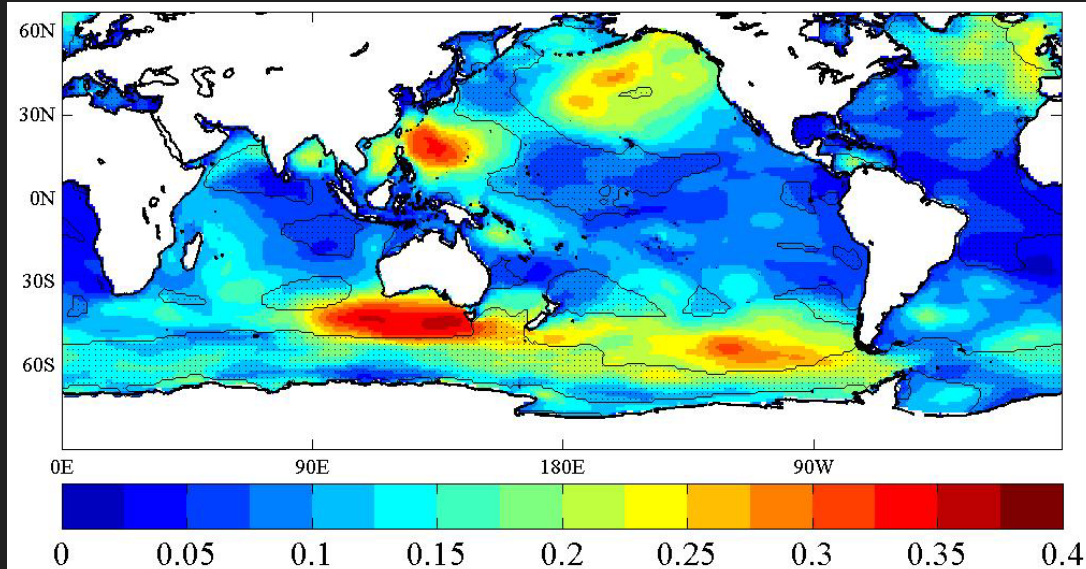
# Future change in annual MSWH

Ensemble mean  
future change



[m]

Maximum difference  
of future change  
among  
12 experiments



[m]

# Future changes in MSWH in JJASON at the North Pacific

3 cumulus convection scheme

YS

AS

KF

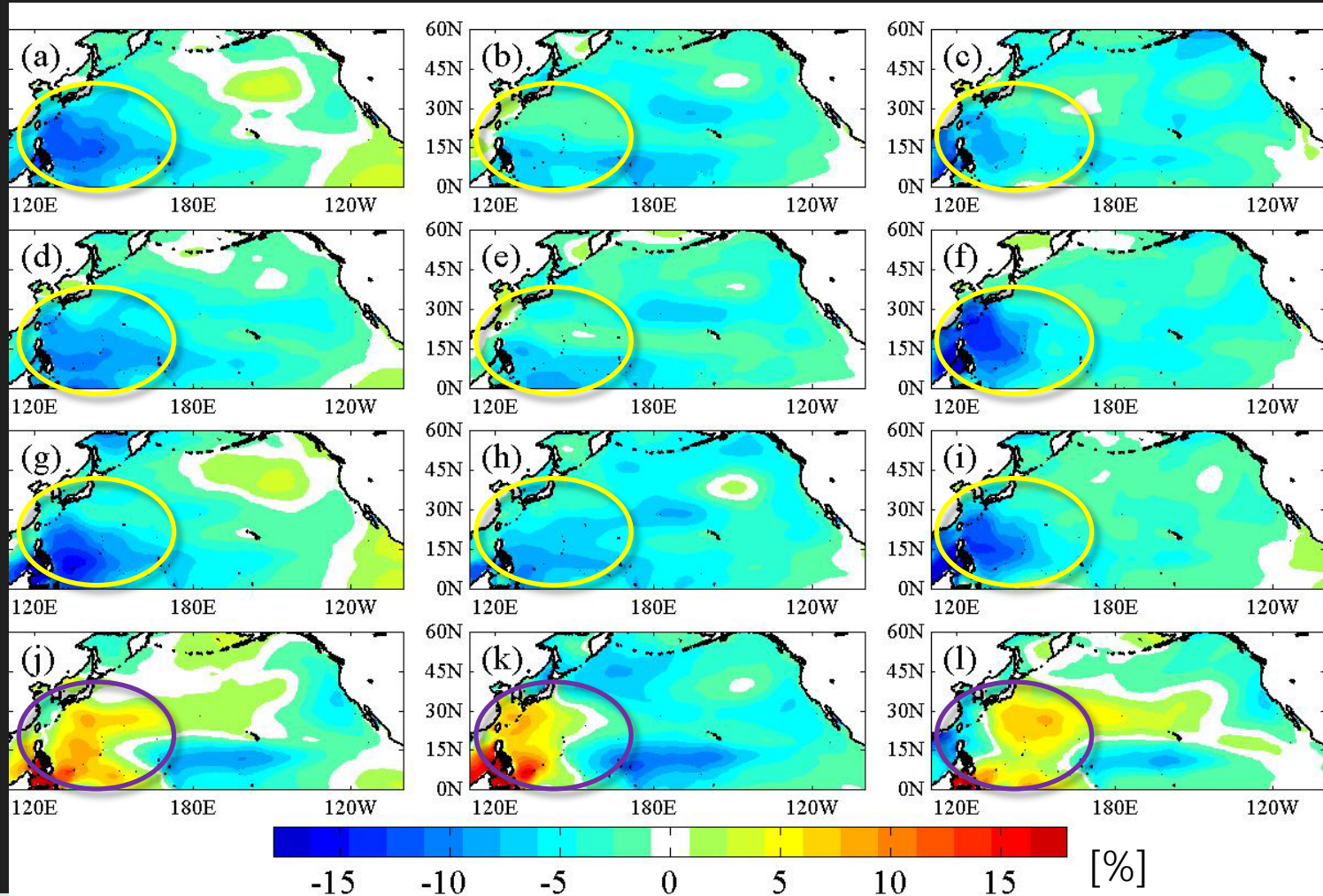
4 SST future conditions

C0

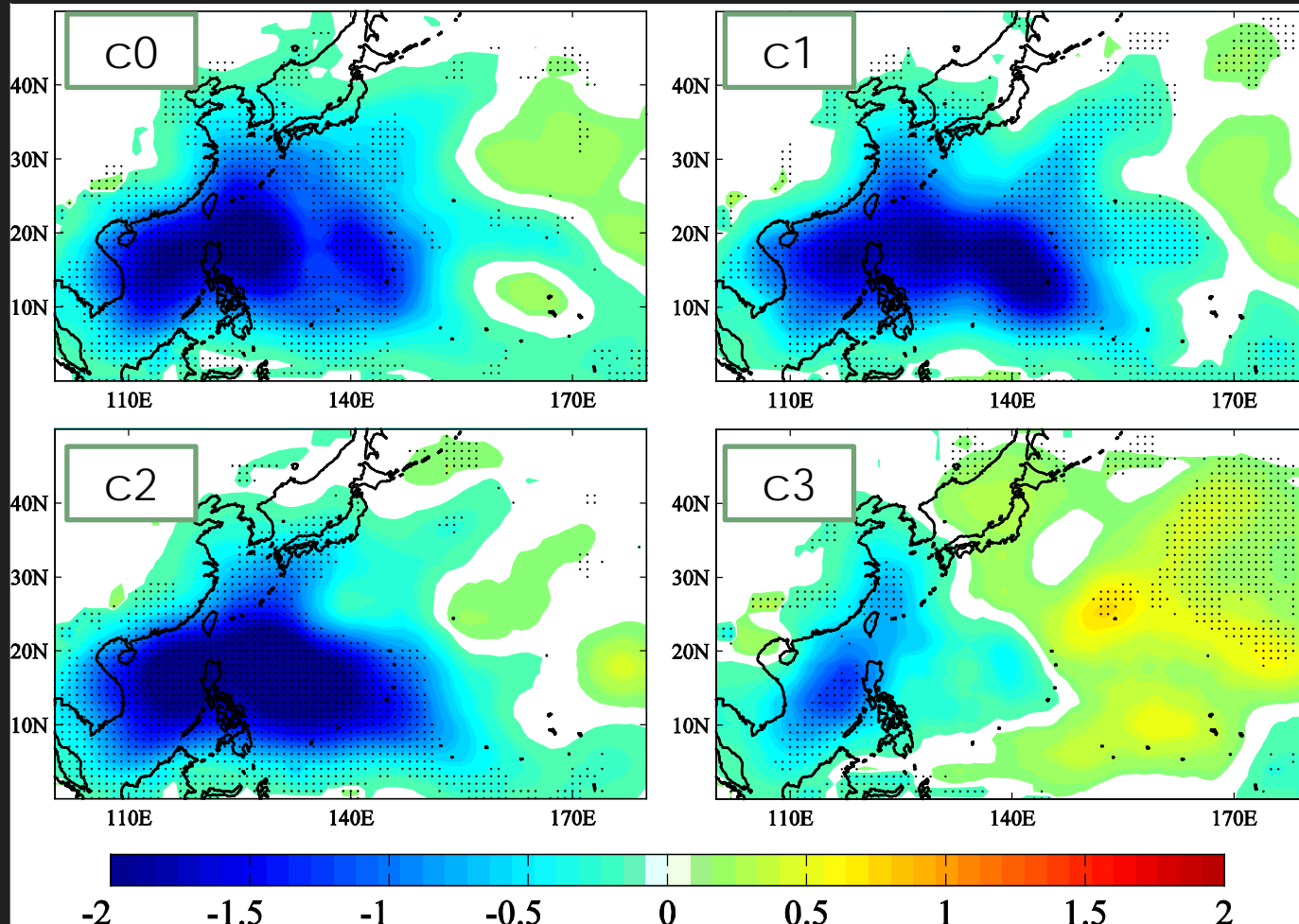
C1

C2

C3



# Future changes in typhoon frequency (YS)



[number/season]

# Contribution of typhoon change to future change in MSWH

## ● MSWH ( $H_m$ )

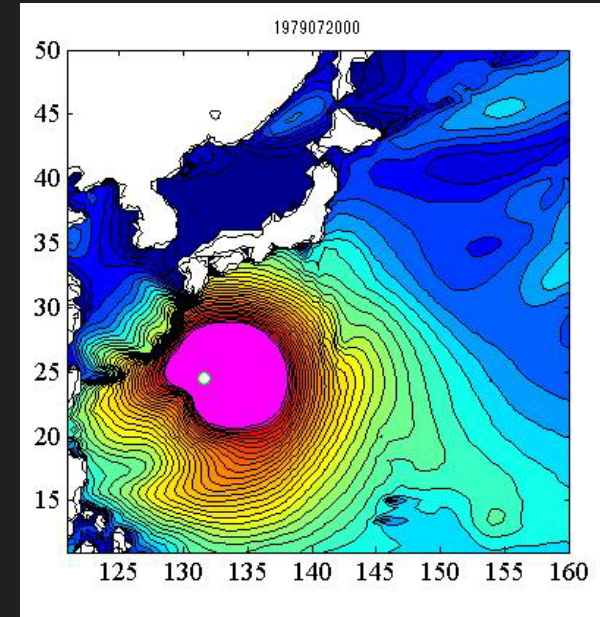
- MSWH generated by TC events ( $H_{tc}$ )
- MSWH under non-TC ( $H_{no}$ )
- TC frequency ( $r_{tc}$ )

$$H_m = H_{tc} \cdot r_{tc} + H_{no} \cdot (1 - r_{tc})$$

## ● Future change in MSWH ( $\Delta H_m$ )

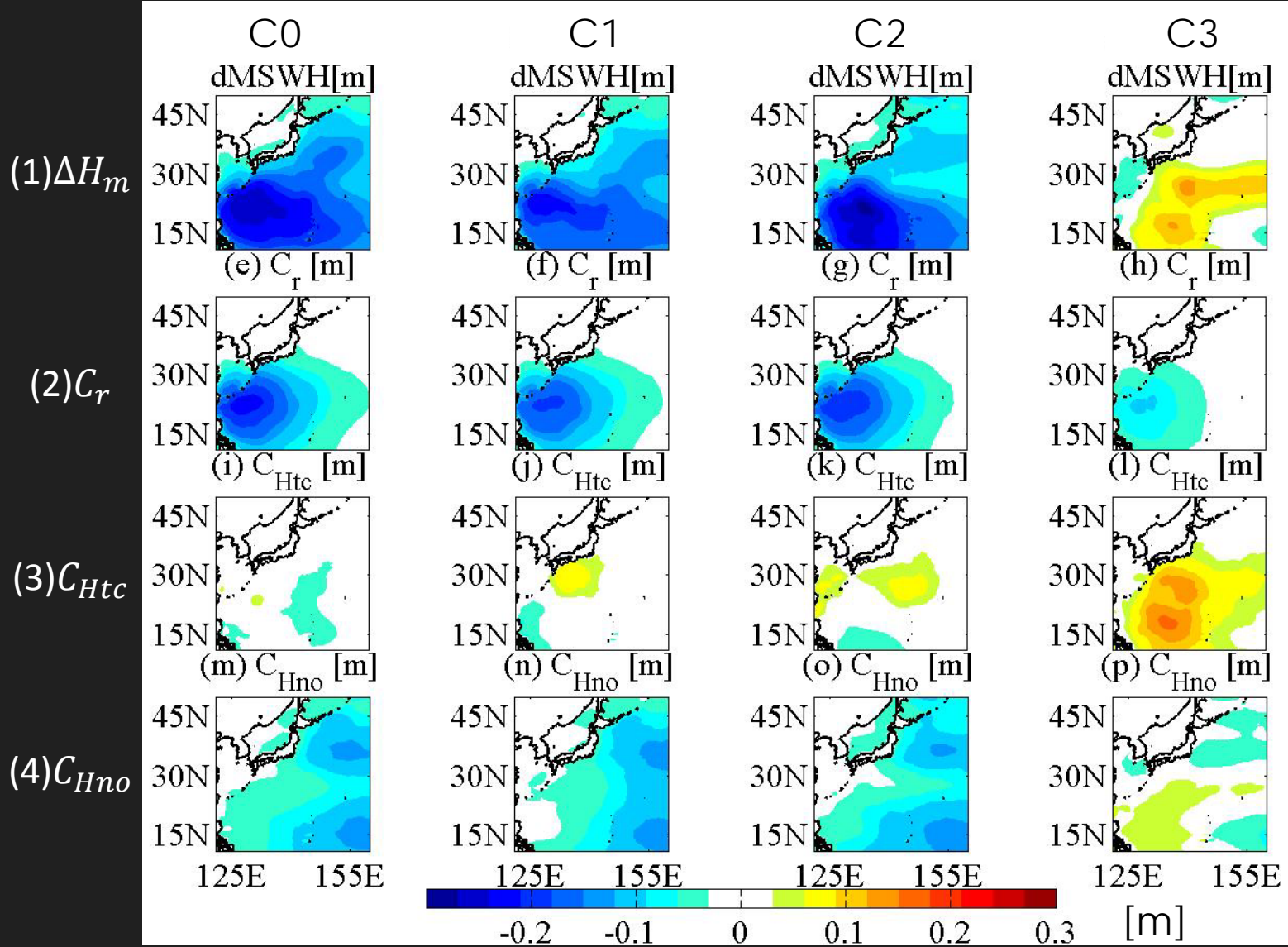
- Component of  $\Delta H_{tc}$  ( $C_{Htc}$ )
- Component of  $\Delta H_{no}$  ( $C_{Hno}$ )
- Component of  $\Delta r_{tc}$  ( $C_r$ )
- Residual component ( $C_\Delta$ )

$$\Delta H_m = C_{Htc} + C_{Hno} + C_r + C_\Delta$$



Waves generated by Typhoon event

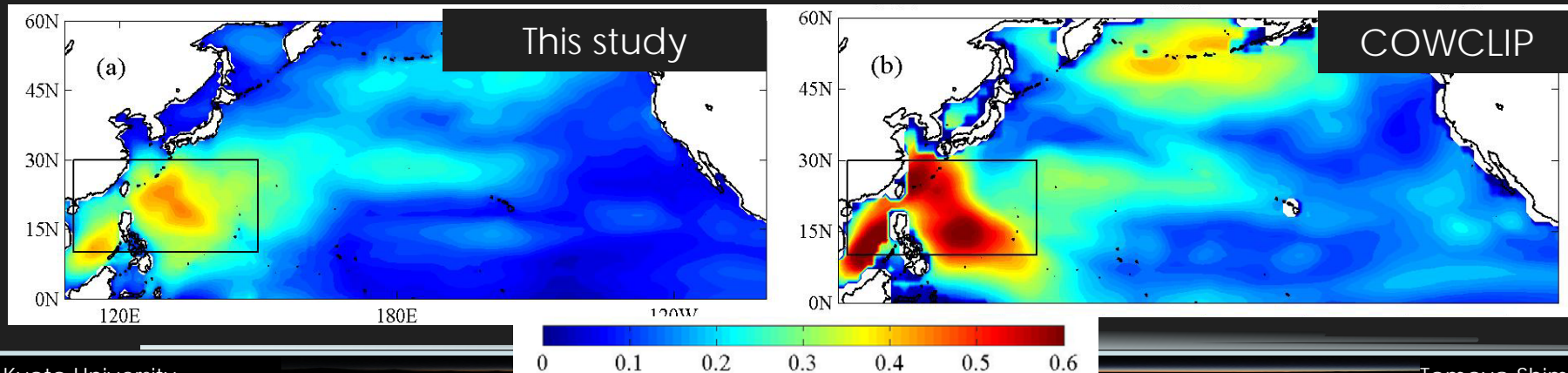
# Contribution of typhoon change to future change in MSWH



# Comparison with COWCLIP studies

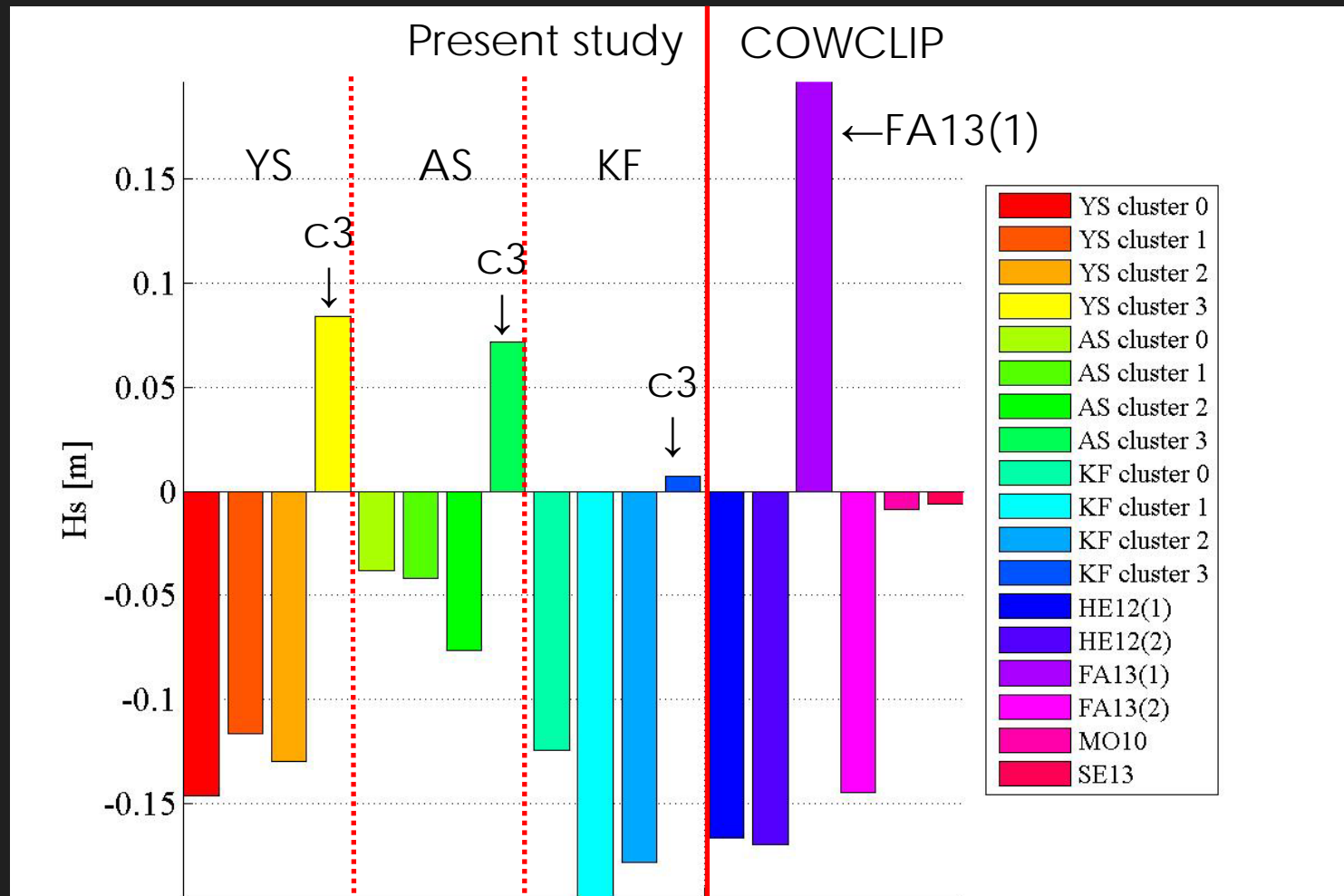
	Hemer et al. (2012)		Fan et al. (2013)		Mori et al. (2010)	Semedo et al. (2013)
	HE12(1)	HE12(2)	FA13(1)	FA13(2)	MO10	SE13
Scenario	SRES A2		A1B		A1B	A1B
SST	MPI ECHAM5	CSIRO MK3.5	GFDL CM2.1	CMIP3 mean	CMIP3 mean	ECHAM5
AGCM	CSIRO CCAM		GFDL HiRAM and WW3 Coupled		MRI AGCM3.1S	ECHAM5 AGCM
Wave	WW3				SWAN	WAM
SST cluster	c2	c1	c3	c0	c0	c2

Maximum difference of future changes in MSWH in JJASON across ensemble members



# Future changes in MSWH at WNP

12 members of present study and 6 members of COWCLIP studies



# Discussion: SST-MSWH

● Y. Fan et al.  
(2013, *J. Clim.*)

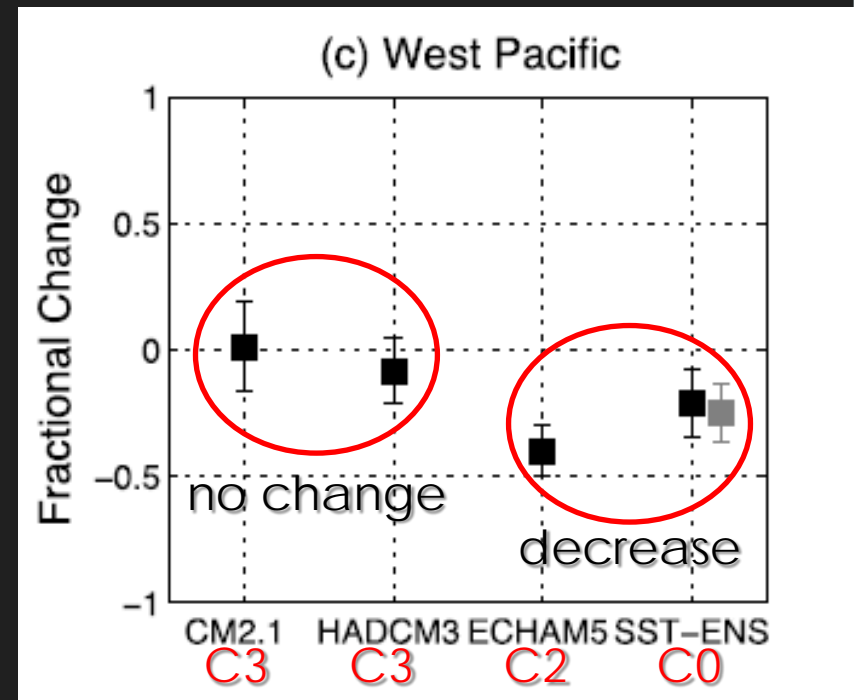
## – SST

- GFDL CM2.1 (C3)
- UKMO HADCM3 (C3)
- MPI ECHAM5 (C2)
- CMIP3 ensemble (C0)

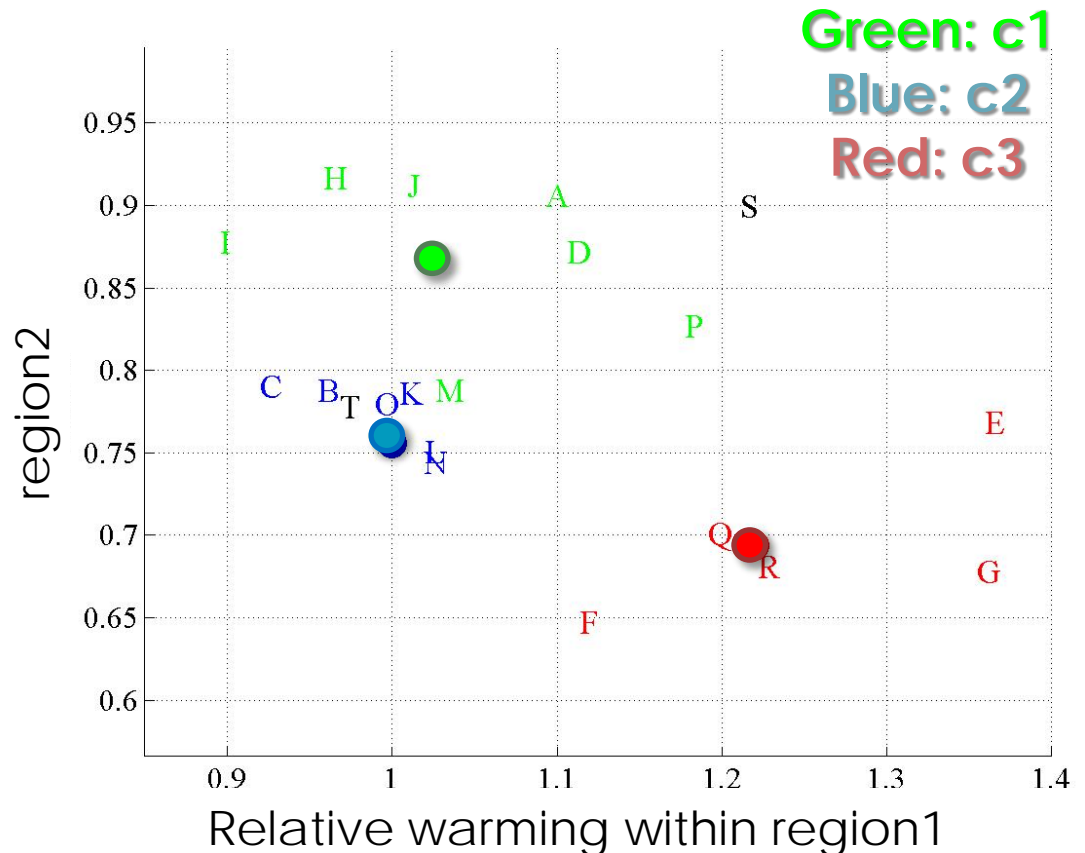
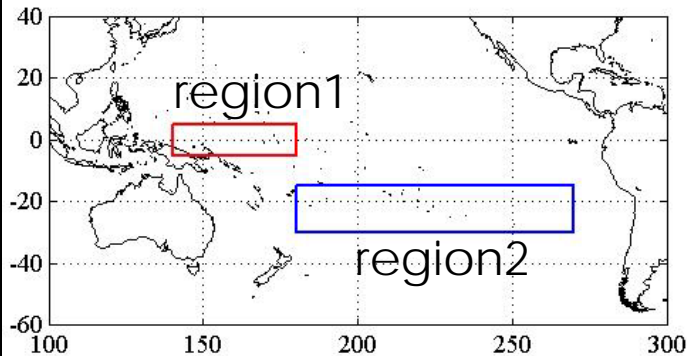
## – West Pacific

- Future change in typhoon frequency depends on SST.
- Future changes in MSWH under SST cluster3 are larger than cluster0 or 2, due to difference of future change in typhoon frequency.

Future change in typhoon frequency



# Representative character of SST clusters



18 letters (A-R) : 18 CMIP3 models under A1B  
2 letters (S, T) : 2 models under A2 used by HE12

# Summary

- Future change in summer MSWH at WNP **depends on SST** condition significantly, through future changes in **typhoon characteristics**.
- There is the robust relationship between future change pattern of SST and summertime wave climate in WNP.
  - Relative growth of mean wave height under SST cluster3 condition.
  - The results were supported by COWCLIP studies.
- Other study also indicted that uncertainties in SST changes are major source of future projection.
  - The Northern Hemisphere jet stream changes (Delcanbre et al., 2013, *J.Clim.*)

The end

# Model Validation

## 1979-2009 Mean SWH

### HPA\_YS - ERA interim

