Assessment of future changes in the sea surface temperature in the Northwest Pacific projected by CMIP6 models

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Abstract

Coupled Model Intercomparison Project Phase 6 (CMIP6) models have projected more rapid warming than CMIP5 models. However, the CMIP6 models still have considerable inter-model differences for future sea surface temperature (SST) projection. In this study, we examine SST biases in the western North Pacific (wNP) simulated by 30 CMIP6 models and evaluate future changes in the SST under the lower emission scenario (SSP1-2.6) and higher emission scenario (SSP5-8.5) from the selected seven CMIP 6 models by assessing the index of agreement. The selected models were ACCESS-ESM1-5, CanESM5, EC-Earth3, KACE-1-0-G, MPI-ESM1-2-HR, MRI-ESM2-0, and UKESM1-0-LL. The SST in the wNP is projected to increase by approximately 1.8°C for SSP1-2.6 and 4.5°C for SSP5-8.5. Noticeably, the projected SST changes are greater in summer (August) than in winter (February) under SSP5-8.5. The stronger surface warming in summer are primarily attributed to thinning of the summer mixed layer (MLD) compared to winter MLD. The inter-model difference in the future SST changes is considerably large in the mixed water region, such as the interfrontal zone between the Kuroshio and the Oyashio and the Yellow Sea. This finding suggests less reliability in future projection in the interfrontal zone.

Data and Methods

- Data: CMIP6 (https://esgf-node.llnl.gov/projects/cmip6/)
- Variables: SST and 10m wind (evaluation only) affecting the upper ocean
- The number of CMIP6 Models: **30** models (SST) and **23** models (10 m wind)
- CMIP6 Scenario: Historical, SSP1-2.6, and SSP5-8.5
- Reanalysis data: WOA05 (SST) and ERA5 (10 m wind)
- Model evaluation: Index of agreement indicating how well the observation and model agree

Table 1. CMIP6 model list

No.	Model name	Horizontal resolution	Country	Institute	note
1	ACCESS-CM2	360*300	Australia	CSIRO	
2	ACCESS-ESM1-5	360*300	Australia	CSIRO	
3	AWI-CM-1-1-MR	25km	Germany	AWI	
4	BCC-CSM2-MR	360*232	China	BCC	
5	CAMS-CSM1-0	360*200	China	CAMS	
6	CanESM5	360*291	Canada	CCCma	
7	CAS-ESM2-0	360*196	China	CAS	SST only
8	CESM2-WACCM	320*384	USA	NCAR	SST only
9	CMCC-CM2-SR5	362*292	Italy	CEMCC	
10	CMCC-ESM2	362*292	Italy	CEMCC	
11	EC-Earth3	364*292	EU	ECMWF	
12	EC-Earth3-Veg	363*292	EU	ECMWF	
13	EC-Earth3-Veg-LR	365*292	EU	ECMWF	
14	FGOALS-f3-L	360*218	China	CAS	
15	FGOALS-g3	360*218	China	CAS	SST only
16	FIO-ESM-2-0	320*384	China	FIO	SST only
17	GFDL-ESM4	720*576	USA	GFDL	
18	INM-CM4-8	360*180	Russia	INM	
19	INM-CM5-0	360*180	Russia	INM	
20	IPSL-CM6A-LR	362*332	France	IPSL	
21	KACE-1-0-G	360*200	South Korea	KMA	
22	MIROC6	360*256	Japan	AORI	
23	MPI-ESM1-2-HR	802*404	Germany	MPI	
24	MPI-ESM1-2-LR	256*220	Germany	MPI	
25	MRI-ESM2-0	360*363	Japan	MRI	
26	NESM3	362*292	China	NUIST	
27	NorESM2-LM	360*385	Norway	NCC	SST only
28	NorESM2-MM	360*385	Norway	NCC	SST only
29	TaiESM1	320*385	Thailand	RCEC	SST only
30	UKESM1-0-LL	362*332	UK	MOHC	

Index of agreement

$$d_{ref} = \begin{cases} 1 - \dfrac{\sum_{i=1}^{n}|P_i - O_i|}{2\sum_{i=1}^{n}|O_i - \bar{O}|}, \text{when} \\ \sum_{i=1}^{n}|P_i - O_i| \le 2\sum_{i=1}^{n}|O_i - \bar{O}| \\ \dfrac{2\sum_{i=1}^{n}|O_i - \bar{O}|}{\sum_{i=1}^{n}|P_i - O_i|} - 1, when \\ \sum_{i=1}^{n}|P_i - O_i| > 2\sum_{i=1}^{n}|O_i - \bar{O}| \end{cases}$$

Model bias — Observation variance

(Willmott et al., 2012)

disagreement — agreement

-1 — 1

P_i: model
O_i: Observation
$\bar{O}$: Observation mean

CMIP6 performance evaluation

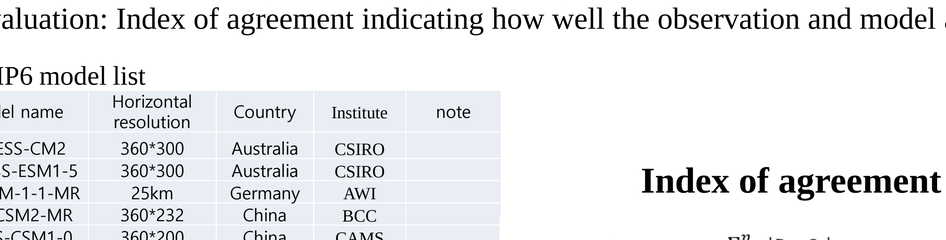
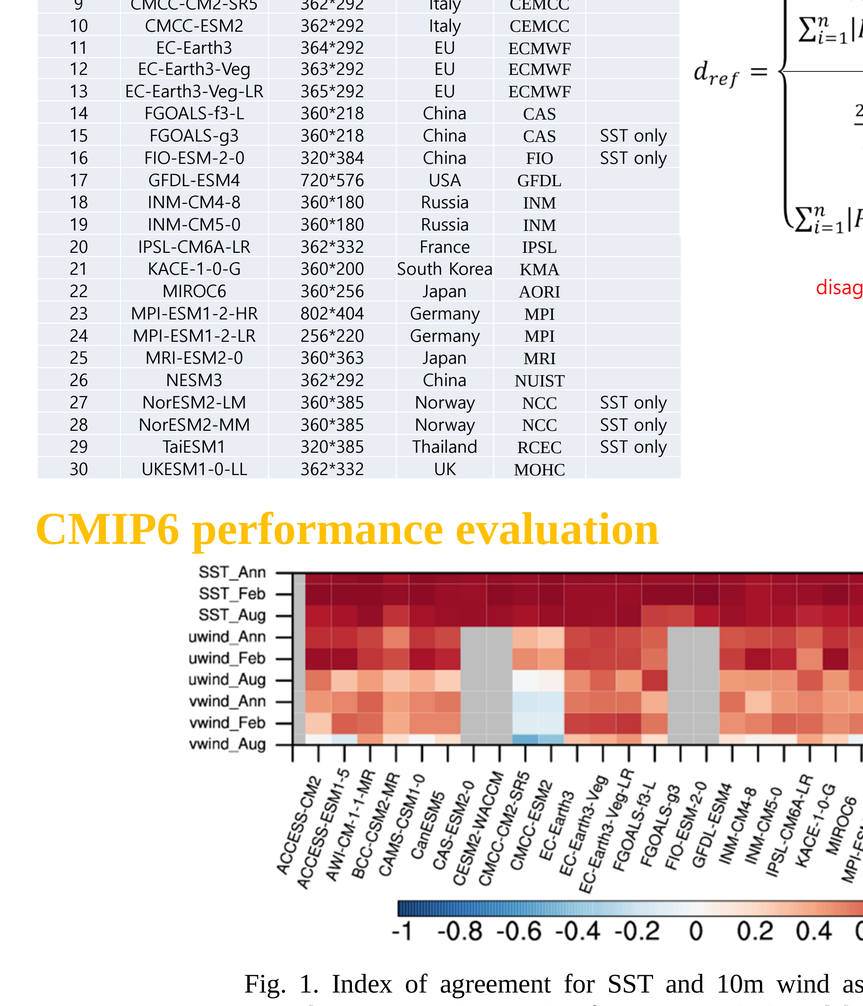


Fig. 1. Index of agreement for SST and 10m wind as February, August, annual average in 1995 to 2014 from CMIP6 (30) models



- CMIP6 models with the top 16th were selected based on the agreement indices of the SST and 10m-wind.

- **Best CMIP6 models:**
  - ✓ MPI-ESM1-2-HR
  - ✓ MRI-ESM2-0
  - ✓ UKESM1-0-LL
  - ✓ EC-Earth3
  - ✓ ACCESS-ESM1-5
  - ✓ CanESM5
  - ✓ KACE-1-0-G

- Significant bias: the polar front such as the mixed water region (interfrontal zone)

Fig. 2. SST bias of annual average from 1995 to 2014 in CMIP6 (30) models

Future projection of SST by using CMIP6 models

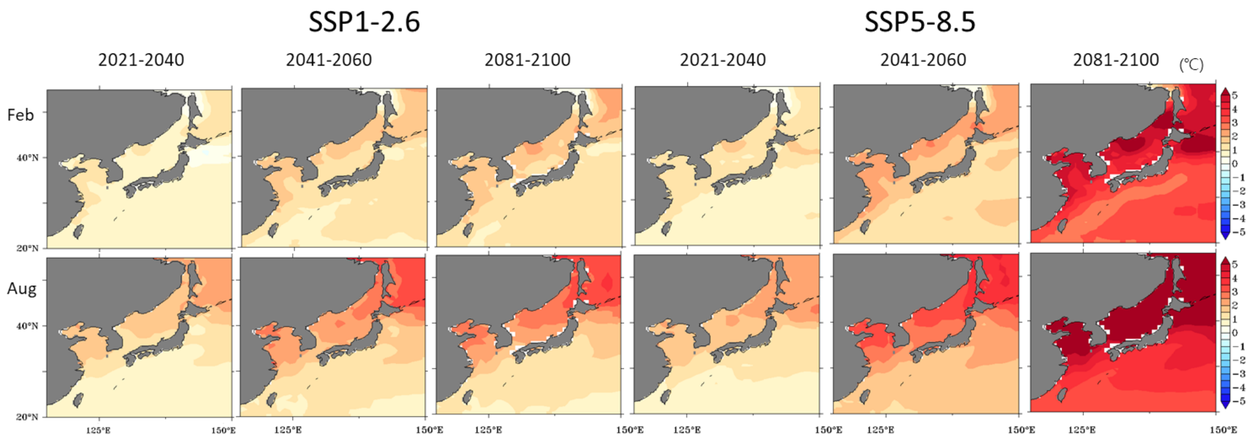


Fig. 3. Ensemble mean future SST changes (future − historical) estimated from the best seven CMIP6. Under SSP1-2.6 (left panel) and SSP5-8.5 (right panel) in order 2021-2040, 2041-2060, 2081-2100. The historical period is 1995 − 2014.

- Best seven CMIP6 models: MPI-ESM1-2-HR, MRI-ESM2-0, UKESM1-0-LL, EC-Earth3, ACCESS-ESM1-5, CanESM5, KACE-1-0-G

- **Future periods:**
  - 2021−2040, 2041−2060, 2081−2100

- **SST change:**
  - SST increases larger at high-latitude than low-latitude region.
  - SST increases larger at summer than winter SST.
  - Reason: warming and salinity reduction → strong stratification → shallow mixed layer → heat capacity increase (Fig. 4 ; Alexander et al., 2018)

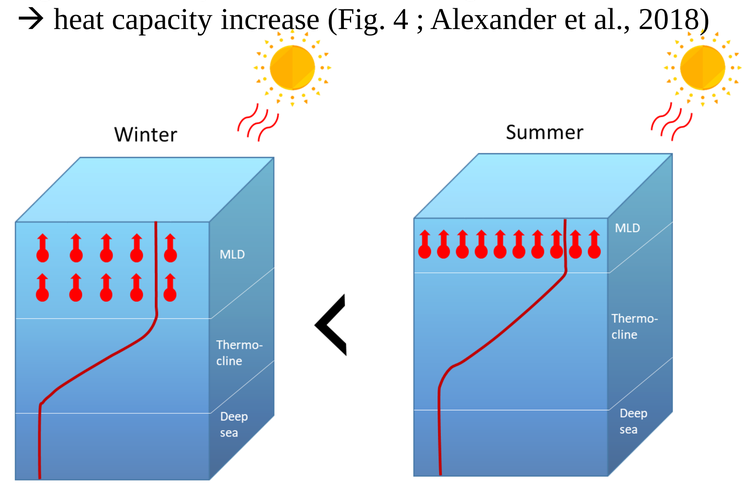


Fig. 4. Schematic diagram of the seasonal differences in SST future changes.

Table 2. Future changes in SST (℃) simulated by CMIP6 (7). Blue is February and red is August.

	SSP1-2.6			SSP5-8.5		
	2021-2040	2041-2060	2081-2100	2021-2040	2041-2060	2081-2100
East Asia	Feb: 0.76 Aug: 1.19	1.21 1.71	1.32 1.73	0.98 1.38	1.64 2.32	3.69 4.67
East/Japan Sea	0.87 1.60	1.49 2.33	1.63 2.54	1.22 1.91	2.01 3.01	4.56 6.13
East China Sea	0.87 1.04	1.24 1.48	1.35 1.47	0.99 1.19	1.74 2.01	3.53 4.00
Yellow Sea	1.05 1.73	1.56 2.42	1.64 2.53	1.22 1.91	2.18 3.10	4.59 5.74

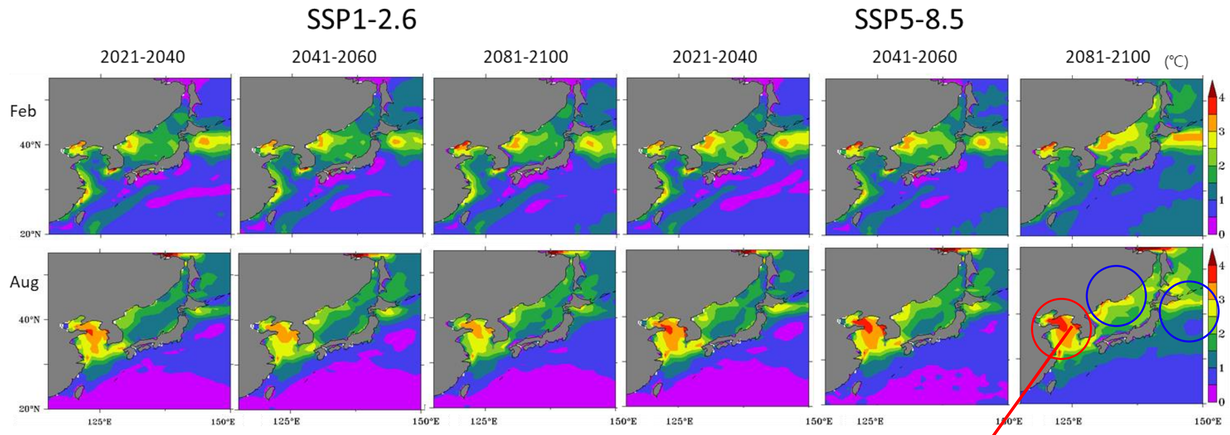


Fig. 5. Inter-model standard deviation in SST changes (future − historical) between best seven CMIP6 models. SSP1-2.6 on the left and SSP5-8.5 on the right, in order near Future (2021−2040), middle future (2041−2060), and distant future (2081−2100). The historical period is 1995−2014.

Yellow sea and mixed water region (interfrontal zone): Large uncertainty between climate model due to coarse resolution

Conclusions

- The best seven CMIP6 models, selected by the Index of agreement, project the increased SST by 1.2 to 4.7℃ in summer and 0.8 to 3.7℃ in winter. This enhanced summer warming is principally attributed to the thinning of summer MLDs, which could accelerate warming by capturing heats within the shallower layer.

- The inter-model difference in the future SST changes is large in the mixed water region. This large deviation suggests less reliability in future projection over the mixed water region, presumably due to the coarse resolution of the CMIP6 ocean models.