Representation of the seasonal cycle of sea surface temperature in CMIP6 models

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Introduction

- Model simulation of the seasonal extrema of sea surface temperature (SST) is an essential aspect of model skill as SST seasonal extrema are important for water mass formation, tropical cyclones and coral bleaching.

- Typically climate model evaluations focus on annual or longer-term mean SST. However, accurate mean SST does not guarantee accurate seasonal extrema or annual cycles. Models that have no biases in mean SST can have biases in seasonal extrema and annual cycles.

Data & Methods

- Maximum and minimum of monthly SST (T_{max} and T_{min}), and the annual cycle of SST (T_{cycle} , that is T_{max} minus T_{min}) were assessed in 20 CMIP6 model historical runs, averaged over 1981-2010, against the World Ocean Atlas (WOA18) observational climatology.

- To quantify the performance of CMIP6 models for SST seasonal extrema, the global area-weighted average and area-weighted root mean square (RMS) of SST biases were calculated.

Bias of maximum SST

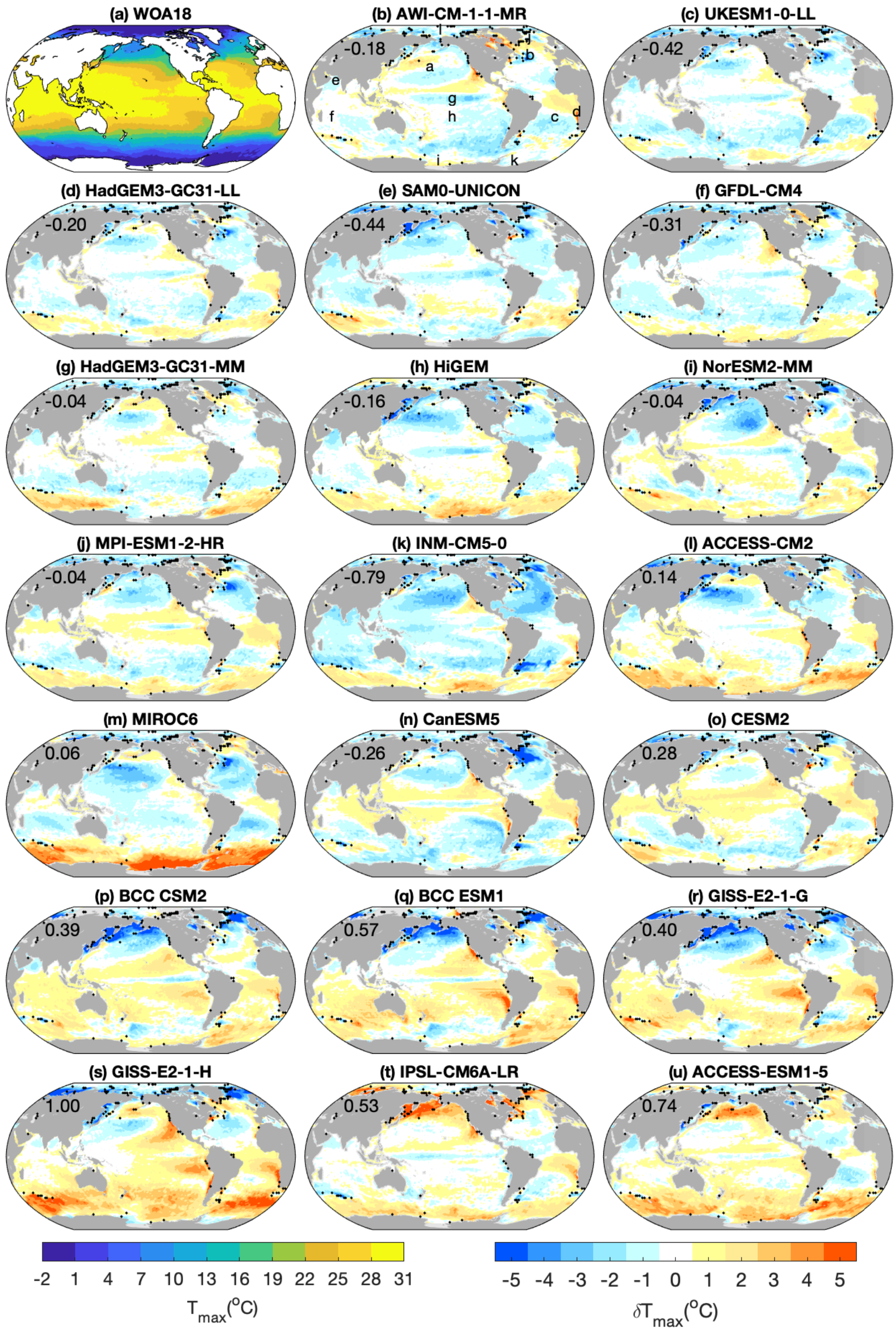


Fig. 1 (a) T_{max} in WOA18 and (b-o) T_{max} bias in models (model minus WOA18). Black dots are the T_{max} mask for high uncertainty of 3 recent climatologies (WOA18, WAGHC and HadISST). Numbers indicate the global area-weighted average of the T_{max} biases. Letters on the map are the positions of points for Fig. 4 and Fig. 5.

- The magnitude and pattern of SST biases for seasonal extrema vary from model to model.
- T_{max} bias is more obvious at mid-high latitude than at low latitude. In some models (e.g. MIROC6, BCC-CSM2, BCC-ESM1, GISS-E2-1-G, GISS-E2-1-H and ACCESS-ESM1-5), the amplitude of T_{max} bias at mid-high latitude can be over 5°C.

Bias of minimum SST

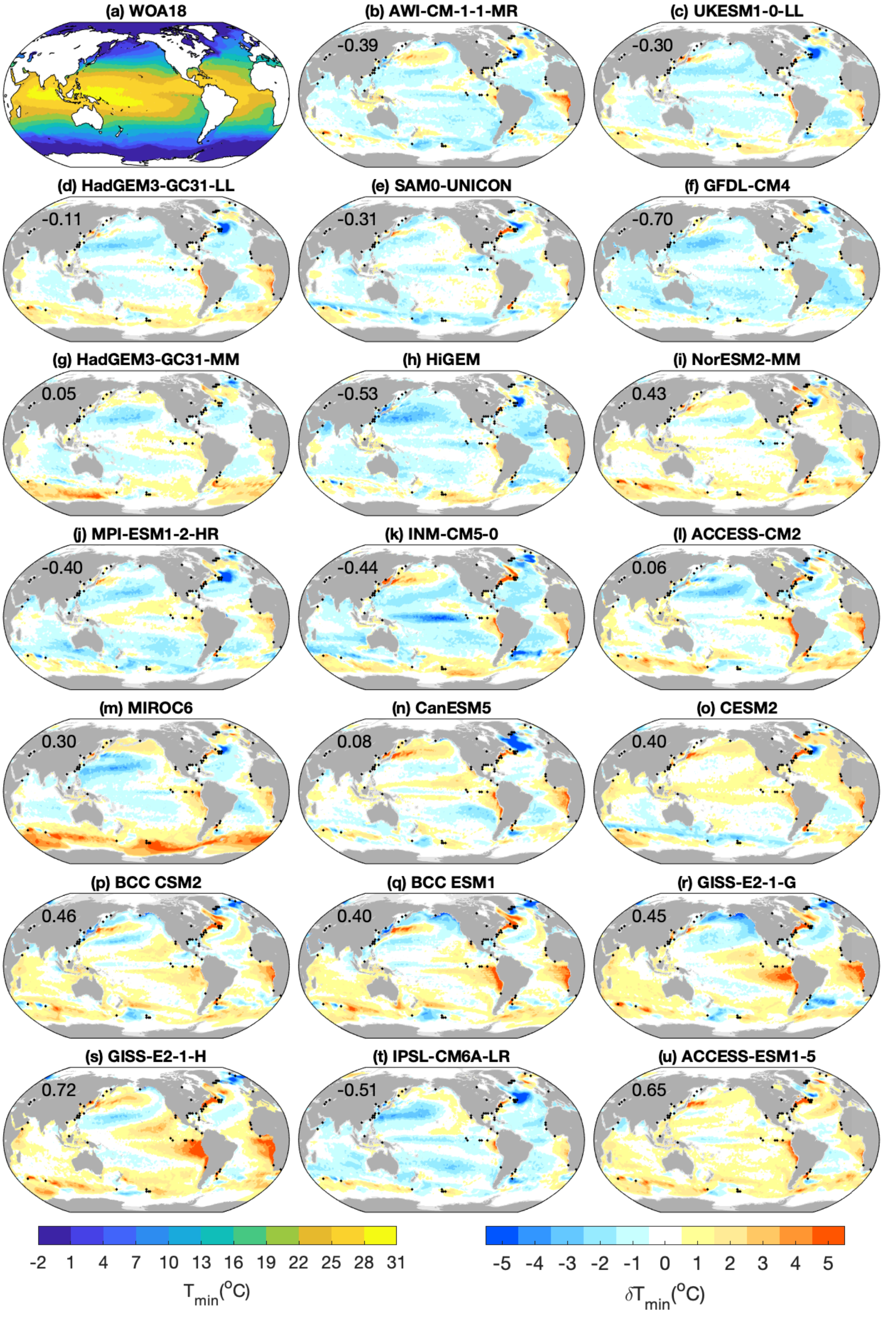


Fig. 2 (a) T_{min} in WOA18 and (b-o) T_{min} biases in models (model minus WOA18). Black dots are the T_{min} mask for high uncertainty of 3 recent climatologies (WOA18, WAGHC and HadISST). Numbers indicate the global area-weighted average of the T_{min} biases.

- The biases are typically smaller in T_{min} than in T_{max} .
- But in eastern boundary regions, the warm bias of T_{min} is larger than the warm bias of T_{max}, because the warm bias due to poorly captured stratocumulus in models can be relieved by the cooling of upwelling in summer.
- The warm bias of the Southern Ocean exists in most of the models and it is much larger in T_{max} than in T_{min}, which might be related to the larger error of cloud-related shortwave radiation in summer.

Bias of SST annual cycle

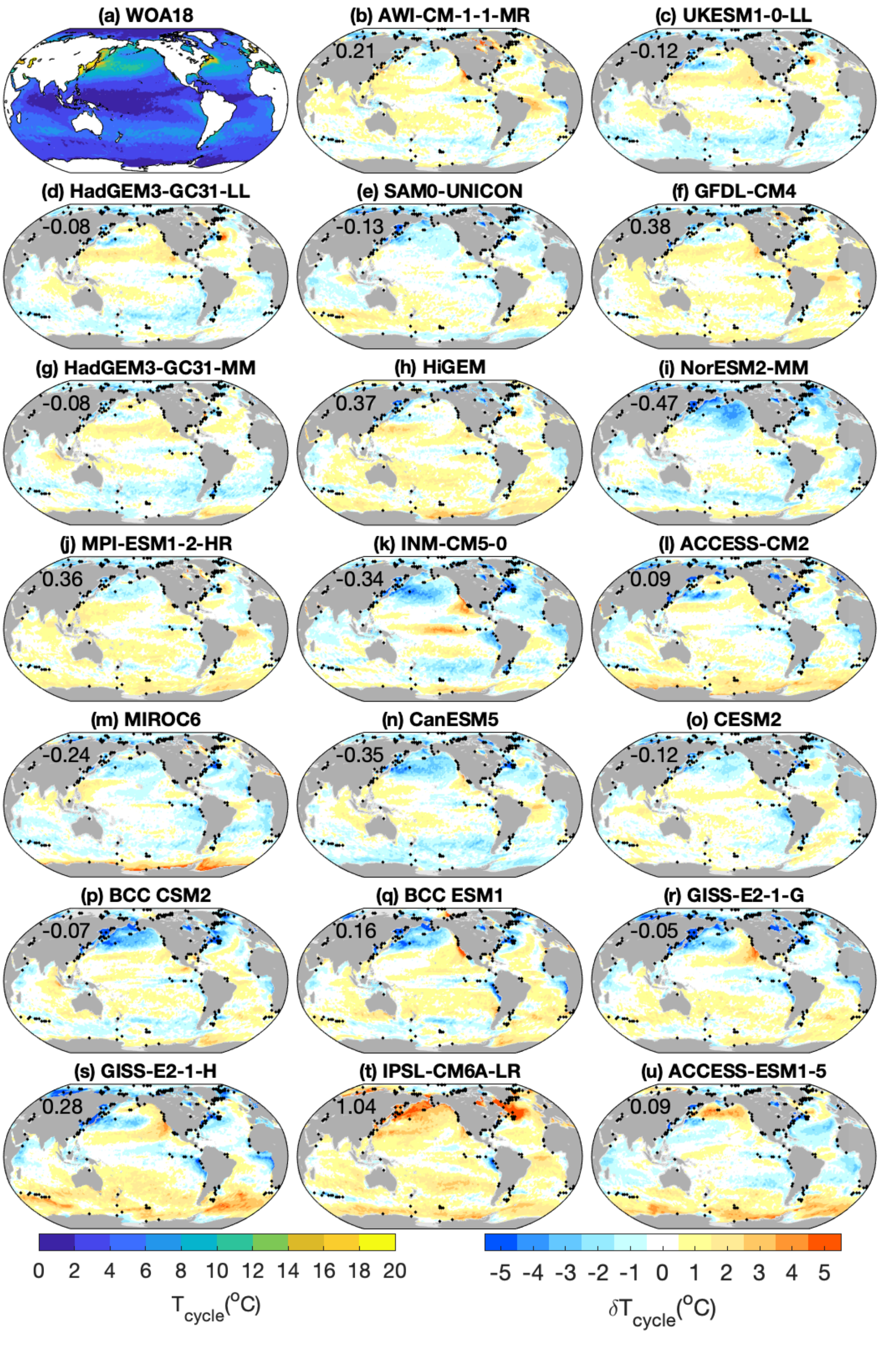
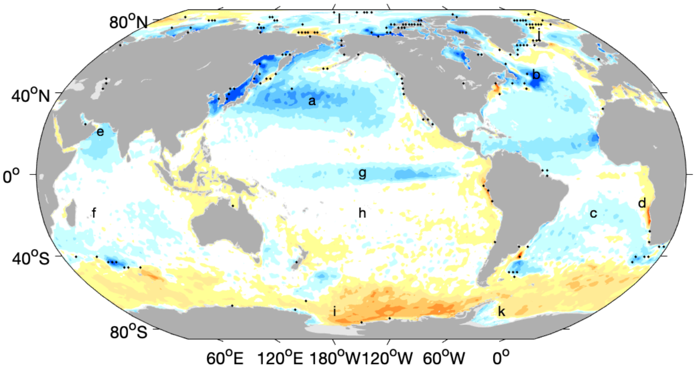


Fig. 3 (a) T_{cycle} (T_{max} minus T_{min}) in WOA18 and (b-o) T_{cycle} biases in models (model minus WOA18). Black dots are the combination of T_{max} and T_{min} masks for high uncertainty of 3 recent climatologies (WOA18, WAGHC and HadISST). Numbers indicate the global area-weighted average of the T_{cycle} biases.

- T_{cycle} is relatively smaller than T_{max} and T_{min}.
- Models with a larger Southern Ocean warm bias in T_{max} than in T_{min} have a positive T_{cycle} bias.
- IPSL-CM6A-LR has a large positive T_{cycle} bias (which means too large SST annual cycle), because of the big difference of biases in T_{max} and in T_{min}.

Time series of SST



- At point b in the North Atlantic, the SST cold bias of IPSL-CM6A-LR can be over 10°C in winter, but decreases to about 2°C in summer.
- At point e in the Arabian Sea, the largest SST bias during the year exists in August for MPI-ESM1-2-HR.
- At point g in the tropical Pacific, INM-CM5-0 has the largest cold bias (over 4°C) during September-October.
- At point i and k in the Antarctic, SST in MIROC6 has the largest bias among models.
- At point k and l in the Arctic, we can see that models have different freezing points.

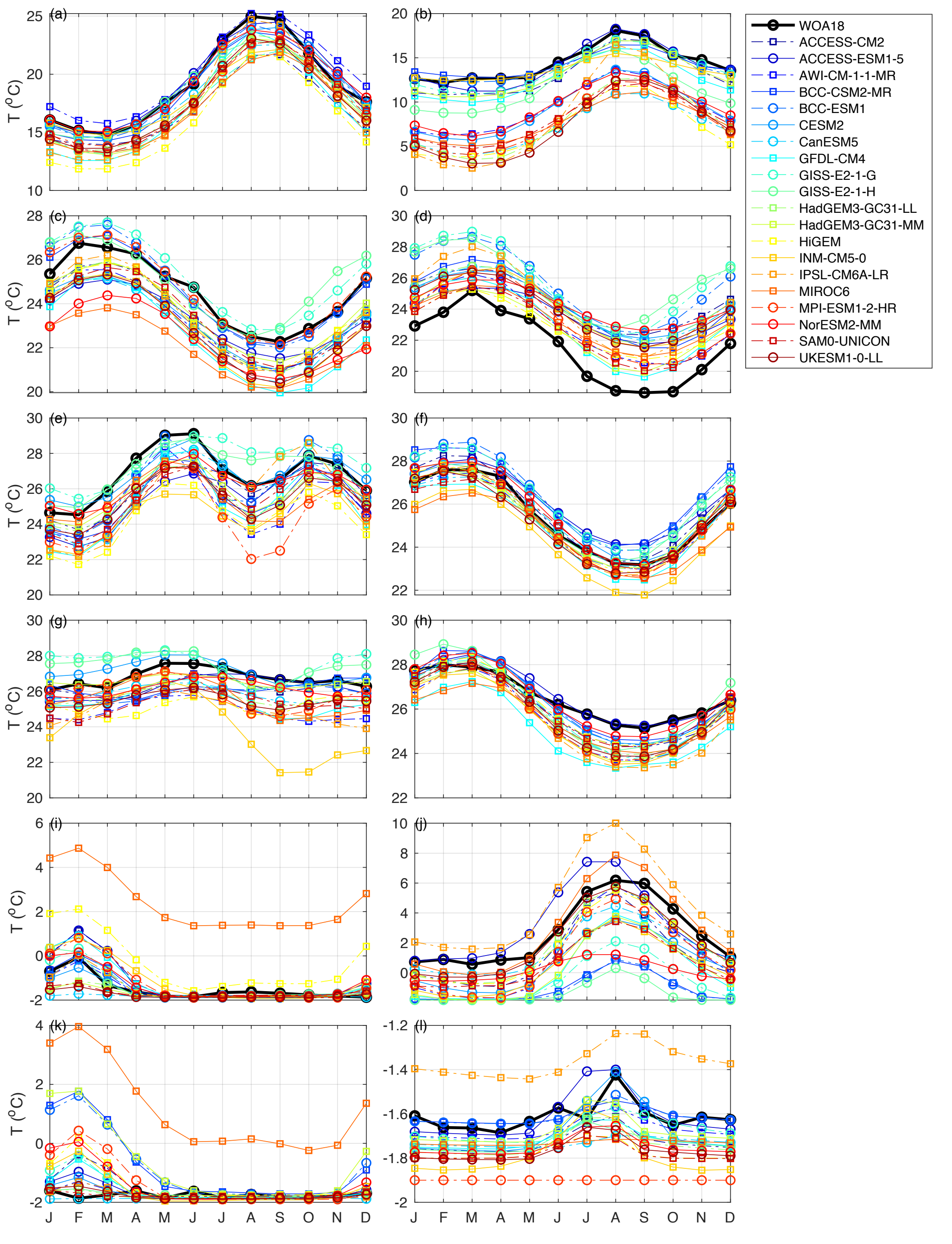
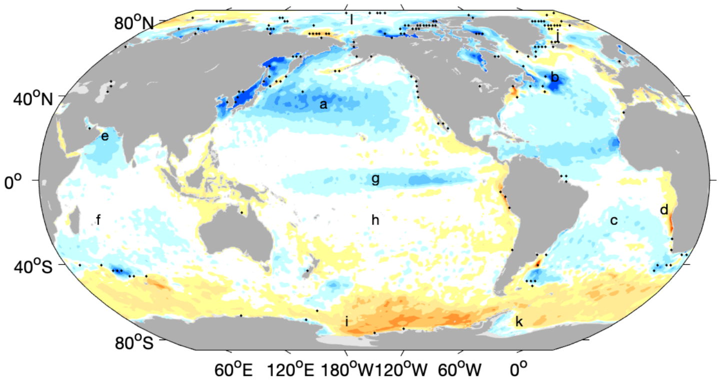


Fig. 4 Time series of SST at points in Fig.1 (b) for WOA18 and models.

Time series of SST with its annual mean removed



- Although models have a large bias in SST, their bias of the range of SST annual cycle is relatively small.
- At point g in the tropical Pacific, INM-CM5-0 has a too large SST annual cycle, with the bias being over 3°C.
- At point h in the South Pacific, models have too large SST annual cycle, which may be related to the error of SPCZ position .
- At point i and k in the Antarctic, MIROC6 has a too large SST annual cycle, as there is no ice formed in the model.

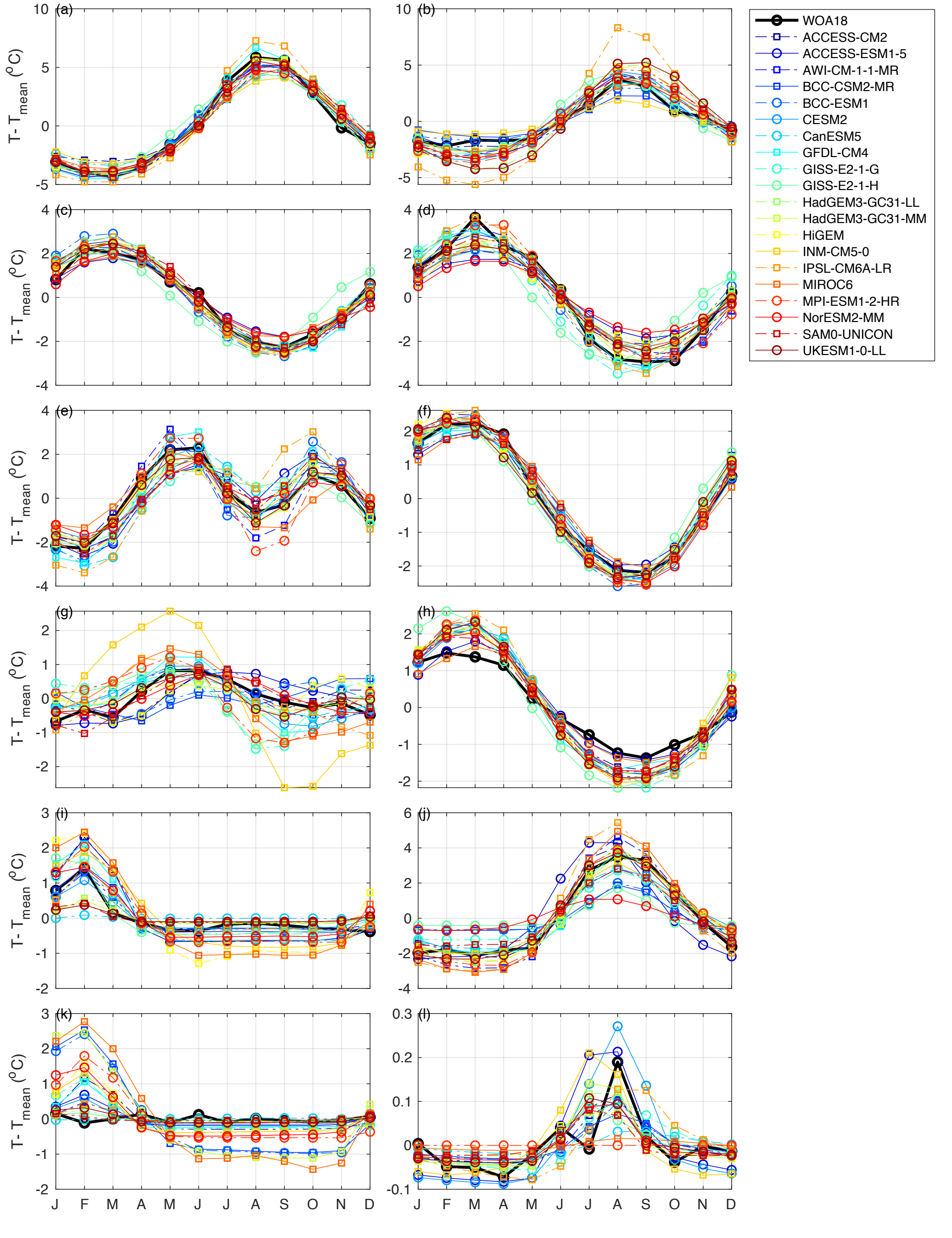


Fig. 5 Time series of SST with its annual mean removed at points in Fig.1 (b) for WOA18 and models.

Global area-weighted RMS of SST biases in models

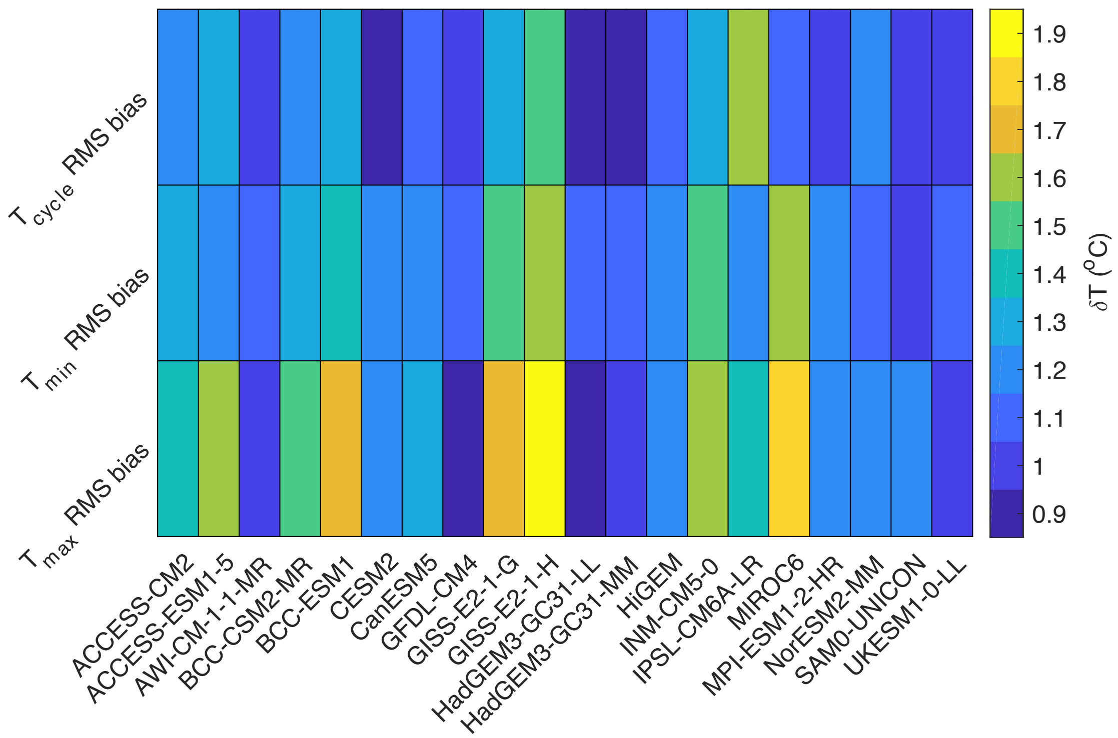


Fig. 6 The global area-weighted root mean square of the bias (model minus WOA18) of SST seasonal extrema and SST annual cycle.

- In most models, the RMS bias is larger in T_{max} than in T_{min}, and T_{cycle} is relatively smaller than T_{max} and T_{min}.
- GISS-E2-1-H has the largest T_{max} bias among models.
- IPSL-CM6A-LR has the largest T_{cycle} bias among models.

Conclusion and discussion

- The magnitude and pattern of SST biases for seasonal extrema vary from model to model.

- The SST bias is typically larger in summer than in winter, at mid-high latitude than at low latitude.

- In eastern boundary regions, the warm bias in summer is less than the warm bias in winter, because the warm bias by poorly captured stratocumulus in models can be relieved by the cooling of upwelling in summer.

- Models have biases of SST seasonal extrema in the polar regions, which can be associated with the sea ice processes. However, extra attention needs to be paid when doing the model assessment of SST in the polar regions, as WOA18 data there can be unrealistic due to the lack of observations.