Uncertainty in projected tropical Pacific SST trends important for winter North Pacific atmospheric circulation

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1. Introduction

- Future projections of the North Pacific atmospheric circulation are uncertain [1] due to the presence of large internal variability [2] and model structural differences in the response to external forcing [3].
- The causes of the model uncertainty are not well known.
- Here we investigate the role of model differences in sea surface temperature (SST) response for spread in North Pacific winter atmospheric circulation. SST spread has been shown to be important in the Southern extratropical atmosphere [4].

We address the following questions:

1. What is the effect of intermodel differences in global average SST trends on North Pacific atmospheric circulation?
2. What are the relative roles of projected global average SST trends vs regional SST patterns for North Pacific circulation?
3. In which regions are projected SST patterns particularly important for driving the North Pacific circulation change?

To isolate the externally-forced atmospheric circulation response we use the Multi-Model Large Ensemble Archive.

2. Methods

- Inter-model spread in the SST and atmospheric circulation response is assessed as the standard deviation of the ensemble mean winter (DJF) anomaly (2080-2099) wrt present-day across the Multi-Model Large Ensemble Archive (MMLEA) models [CanESM2, CESM1, CSIRO-MK-3.6, GFDL-ESM2M, GFDL-CM3 and MPI-ESM-LR]. Ensemble size varies between 20 to 100 members. Models use the RCP8.5 scenario.
- An intermediate complexity global atmospheric model (IGCM4) is forced with present day and future SSTs from the different MMLEA models, to isolate the atmospheric response.
- To determine the dominant regions of SST anomalies for circulation response uncertainty, we perform IGCM experiments where the SST anomaly from our reference model (CESM1) in one region is substituted with another model (regions: tropical Pacific, tropical Atlantic, North Atlantic, Indian Ocean and North Pacific).

3. North Pacific response to global normalised SST anomalies

- MMLEA models show a mean poleward jet shift in the North Pacific in the western basin. Large intermodel spread is found in the west Pacific, the central-North Pacific and north-east of Japan
- IGCM4 forced only with MMLEA SSTs reproduces a similar spatial pattern of ensemble mean zonal wind change. Suggests model can reproduce general large-scale response with only SSTs.
- SST patterns contribute to most of the patterns of the zonal wind change in IGCM. Differences in global mean SST contribute to the amplitude of the pattern (not shown).
- IGCM4 with MMLEA SSTs shows spread in west Pacific and to the north-east and south-east of Japan. SST patterns contribute to model structural differences in these regions.
- Hot spot of MMLEA spread in central North Pacific is not captured in IGCM. Related to structural model differences (e.g. physics).

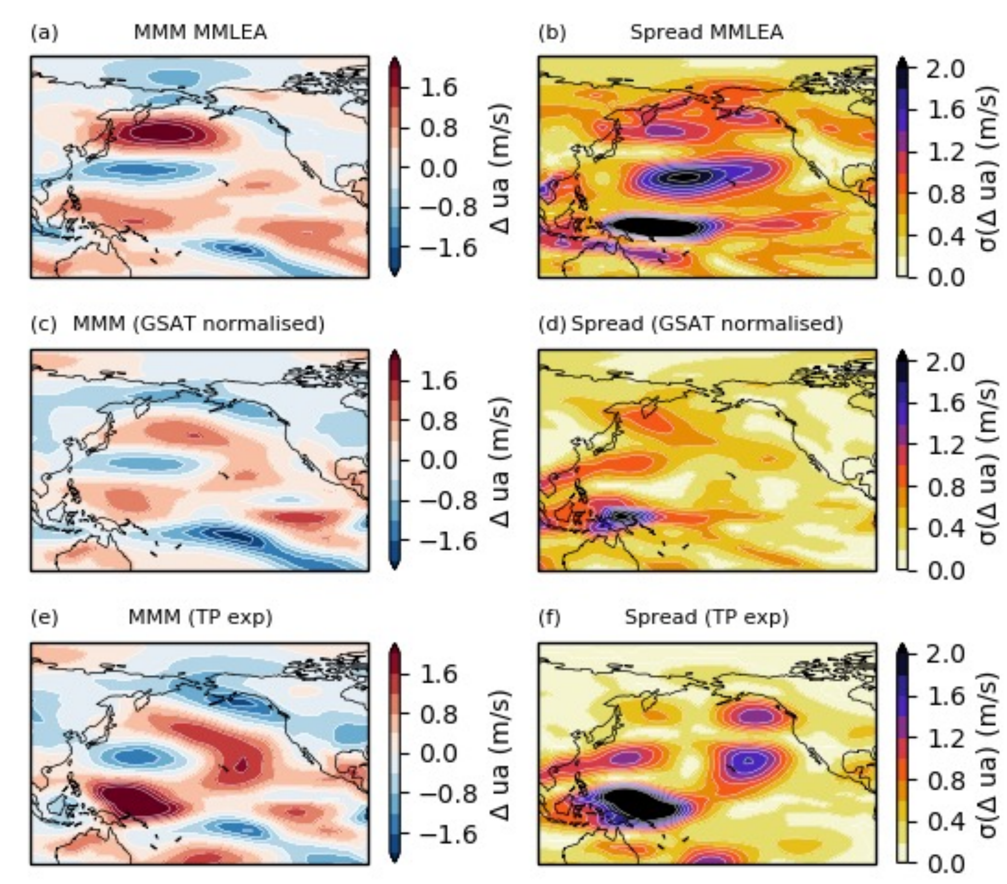

Figure 1. 850 hPa zonal wind. (a) MMLEA model multi-model mean future-past anomaly (c) the average anomaly in IGCM4 when forced with SSTs from all the MMLEA models; (e) as in (c) but for tropical Pacific SST anomaly alone.
Right column as in left but for inter-ensemble standard deviation rather than ensemble mean.

4. Role of tropical Pacific SST patterns

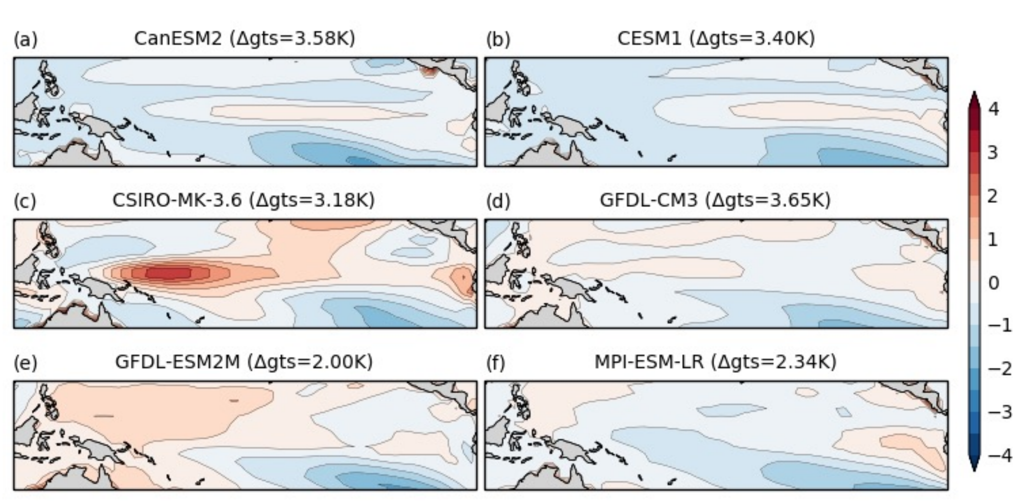

Figure 2. DJF tropical Pacific sea surface temperature for [2080-2099] – [1995-2014] with respect to the global averaged SST (ΔTs – ΔgTs).

5. Tropical Pacific SST experiments

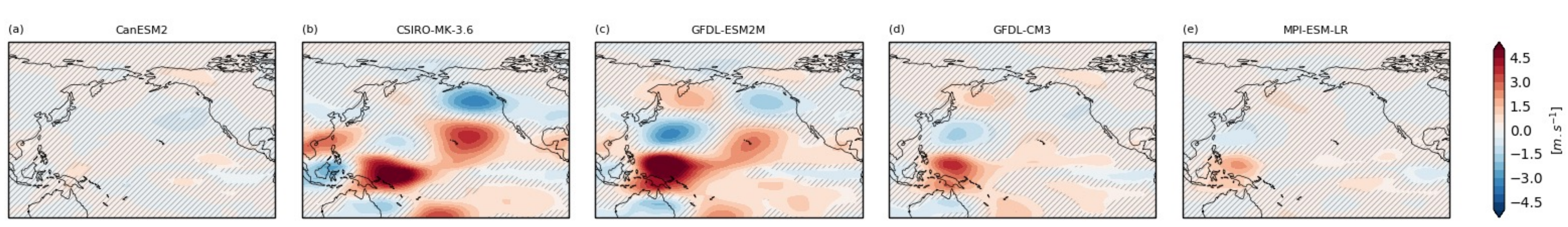

Figure 3. Difference in future – past DJF 850 hPa zonal wind anomalies (m/s) for the tropical Pacific SST experiments with respect to anomalies in the CESM1 reference model.

The main contributor to SST-induced spread in North Pacific circulation in IGCM is found to be the tropical Pacific (Fig.1 d and f; Fig. 3). Other regional SST experiments have a modest effect on the ensemble spread (not shown). The spread due to tropical Pacific SST uncertainty is larger in the eastern North Pacific than in the global SST experiments. This suggests SSTs in another region damp model spread there.

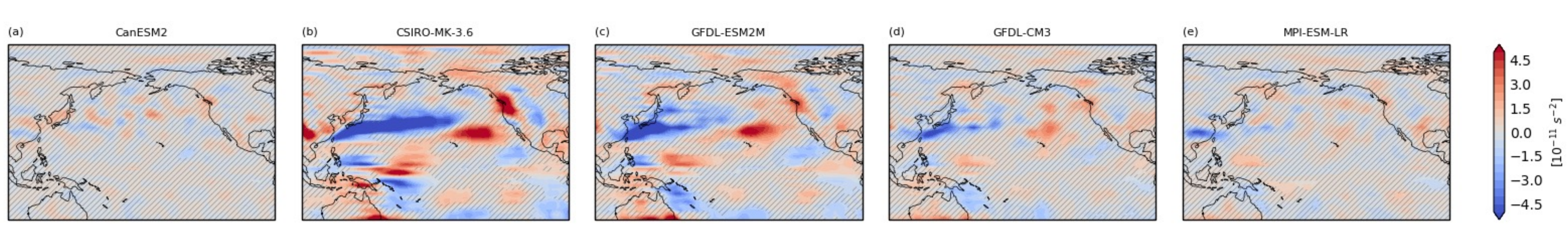

Figure 4. As in figure 3, but for the Rossby wave source [s^{-2}].

Models with enhanced west Pacific warming (CSIRO-Mk3.6, GFDL-ESM2M) show regions of anomalous Rossby wave source in the tropical west Pacific (Fig. 4) driven by anomalous enhanced convection and precipitation. These are weaker in models that show proportionately larger east Pacific warming.

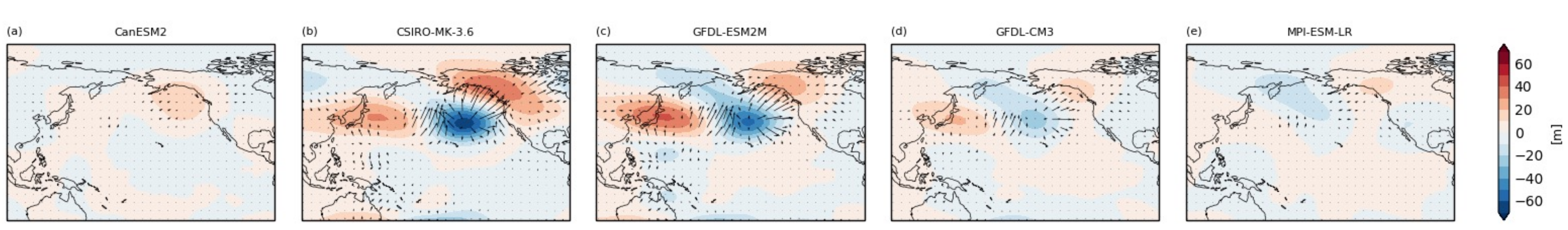

Figure 5. As in Figure 3, but with the 500 hPa eddy geopotential height (contours; m) and horizontal component of wave activity flux (vectors).

Uncertainty in the North Pacific atmospheric circulation response is a result of differences in a poleward propagating Rossby wave train, whose amplitude is sensitive to the amount of western Pacific warming. Models with strongest west Pacific warming show a larger amplitude wave (Fig 5).

6. Conclusions

1. Model structural uncertainty in future SST patterns contribute to uncertainties in the projected North Pacific extratropical atmospheric circulation.
2. The magnitude of the global normalised SSTs dictates the strength of the circulation response, and regional SST patterns dictate the patterns of the circulation response.
3. Model spread in projected tropical Pacific SST changes are the main source of SST-related spread in North Pacific atmospheric circulation changes. Warming in the tropical west Pacific greatly influences the circulation.

References

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Acknowledgements

The work was funded by the CONSTRAIN project and the Leverhulme Trust.