A relationship between surface flux biases and the double ITCZ bias in climate models

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Background

The ITCZ bias in climate models

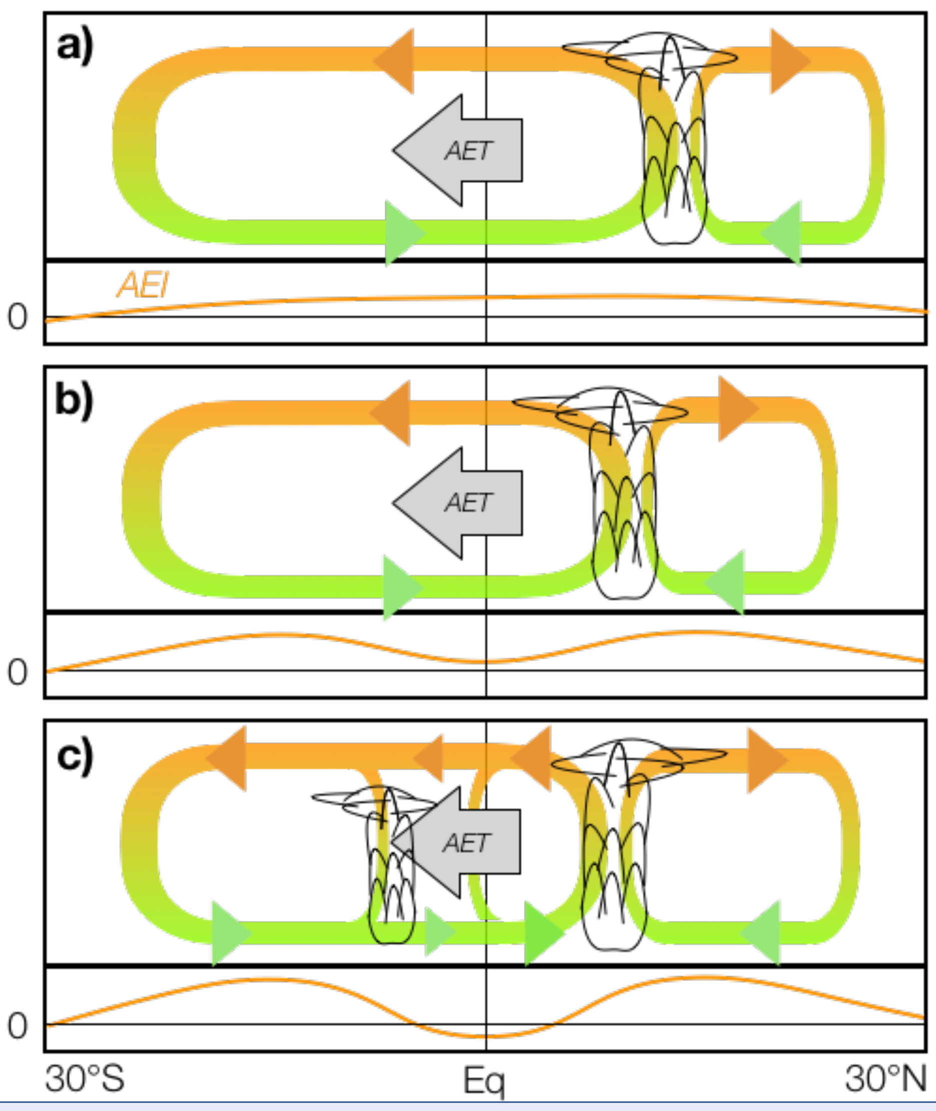
- Persistent biases in ITCZ structure and width in climate models
- Interhemispheric heating imbalance shifts ITCZ away from Equator
- ITCZ shift varies with atmospheric energy transport (AET) and distribution of tropical atmospheric energy input (AEI)
- AEI is set by solar heating, longwave cooling, and ocean heat uptake (**including surface fluxes**)

Li and Xie 2014; Fiedler et al. 2020; Huang and Frierson 2013; Bischoff and Schneider (2014, 2016); Byrne and Schneider 2016

Surface fluxes and their computation

- Climate models simulate wide range of mean surface latent flux
- Most bulk surface flux algorithms overestimate the flux by 10-20%
- COARE3.0 algorithm is one of the least problematic algorithms when compared to direct covariance flux measurements
- Most climate models do not use the COARE3.0 algorithm

Brunke et al. 2003; Brodeau et al. 2017



Conclusions

- Q: How widely do model surface fluxes differ for a given set of conditions? *A: up to 50 W m^{-2} for certain conditions (not shown).*
- Q: Are bulk inputs (wind, humidity) or bulk algorithms more responsible for model surface flux biases? *A: On average, algorithms inflate the flux, while inputs can inflate or reduce the flux (Fig. 3).*
- Q: Do model latent heat flux biases contribute to ITCZ biases? *A: Yes, as shown with offline and inline flux corrections (Figs. 4 and 5).*
- Q: How might surface flux biases affect ocean heat uptake and SST patterns in a warming world? *A: A topic for future work.*

Fig. 1. Schematic illustration of annual mean ITCZ position and structure as a function of AEI meridional distribution for a fixed AET (following Bischoff and Schneider 2014, 2016). In each panel, the Northern Hemisphere is warmer than the Southern Hemisphere by a fixed amount, implying a fixed AET for all panels.

Diagnosing Surface Flux Biases

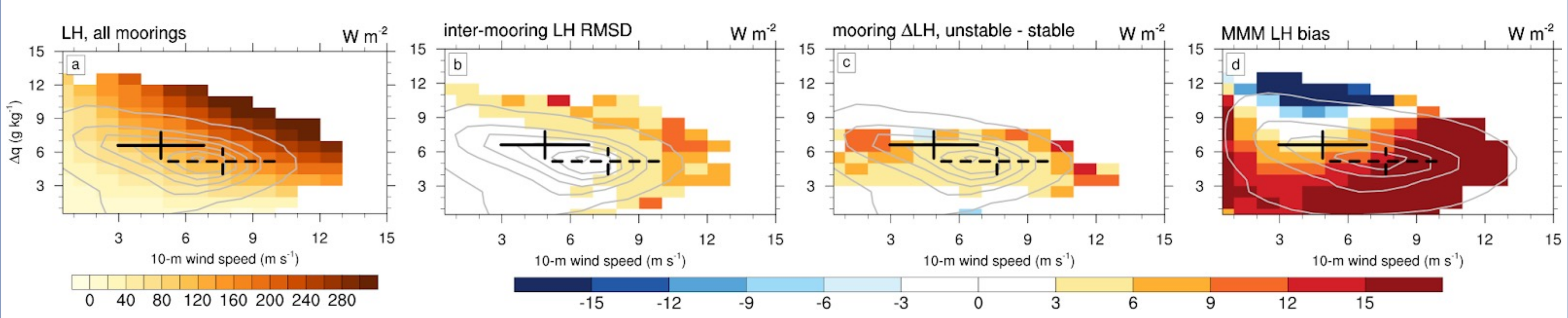


Fig. 2. a) Surface latent heat (LH) flux (shading) as a function of 10 m wind speed and near-surface humidity disequilibrium as estimated using the COARE3.0 algorithm and inputs from all available tropical moorings; b) root mean square difference between individual mooring "flux matrix" and the flux matrix shown in a); c) mean flux difference for stable vs unstable boundary layers, as measured by sign of SST – T_{2m}; d) CMIP6 multi-model mean flux bias. Contours denote 0.1%, 1, 2, 3% etc. relative frequency of wind-humidity input pairs. Solid and dashed crosses denote ±1 standard deviation of bulk inputs for solid and dashed regions shown in Fig. 4b.

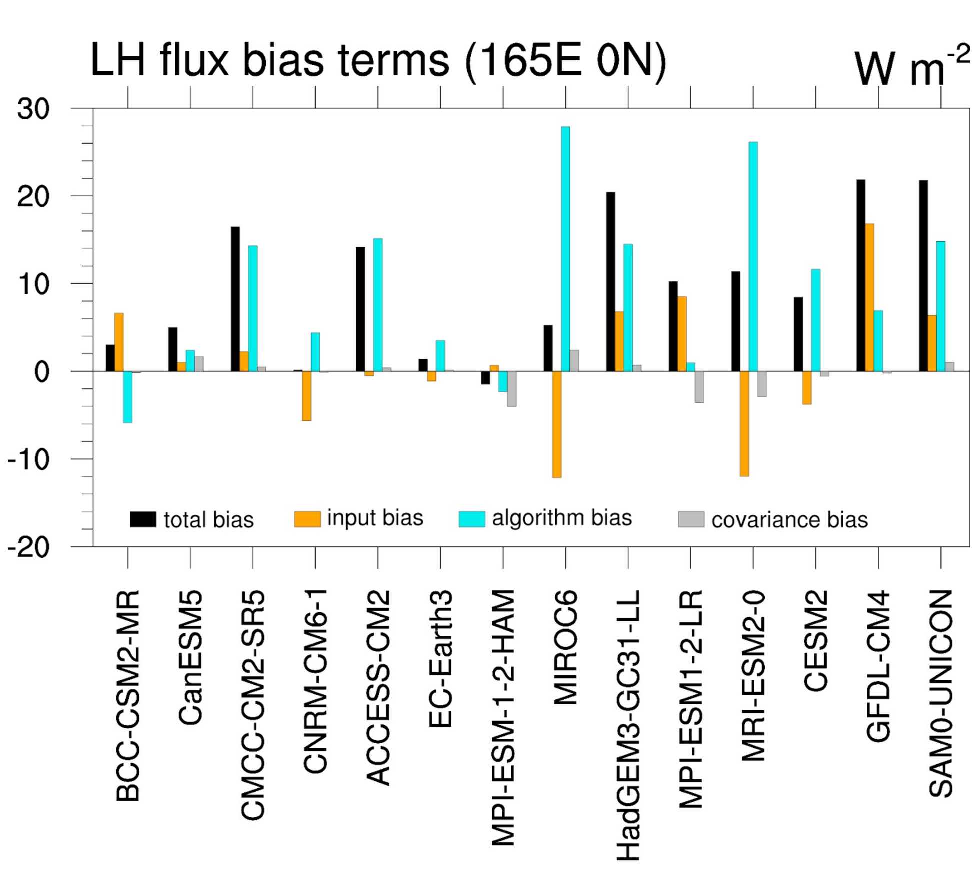


Fig. 3. Contributions from input biases (orange), algorithm biases (cyan) and input-algorithm cross terms (gray) to individual model mean LH flux biases (black) at the tropical Pacific 0N, 165E mooring. Mooring fluxes are computed using the COARE3.0 bulk flux algorithm.

Results

- Multi-model mean (MMM) surface flux biases are much larger than uncertainties arising from regional differences or stability effects in observations (Fig. 2b-d)
- Surface flux biases *are not* uniformly distributed across all states. (Fig. 2d)
- Algorithm and input biases both contribute to model flux biases (Fig. 3)
- Fig. 2a and 2d are leveraged to produce an offline correction to the model flux, i.e., the flux that would have resulted if the COARE3.0 algorithm were used in the model
- Offline correction indicates that flux algorithms overestimate tropical fluxes but especially in the subtropics (Fig. 4)
- Surface flux inline correction (replacing original flux algorithm with COARE3.0 algorithm) in two climate models reduces subtropical fluxes, AEI, and rainfall (Fig. 5b and 5e)
- Inline flux correction reduces ITCZ width bias in both models (Fig. 5e)

Surface Flux Biases and the ITCZ in CMIP6 Models (*offline*)

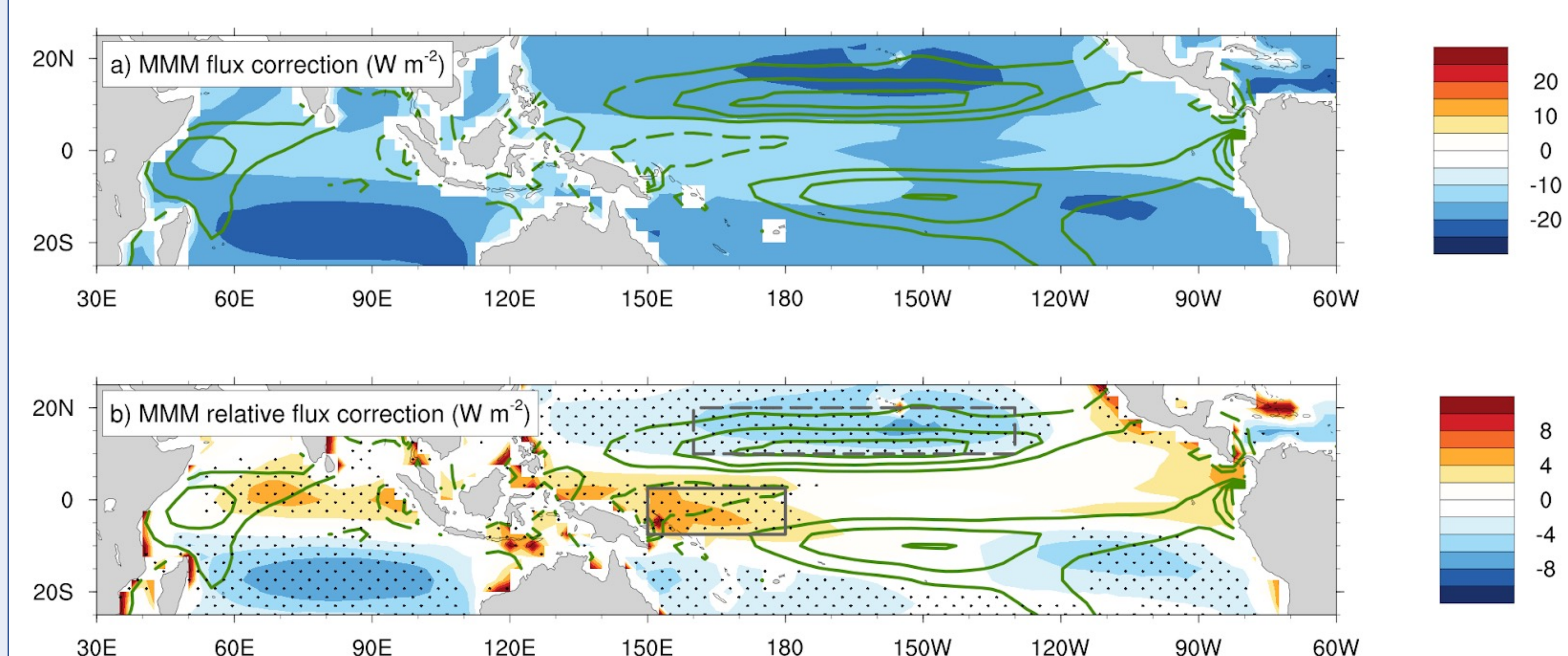


Fig. 4. a) MMM surface flux correction (shading) and annual mean rainfall bias (contours, every 1 mm day^{-1}); b) as in a) but after subtracting the domain mean flux correction. Stippling indicates where the sign of the relative flux correction for a single model agrees with that plotted in b) in at least 12 of the 14 models.

ITCZ with COARE3.0 Fluxes in Two Climate Models (*inline*)

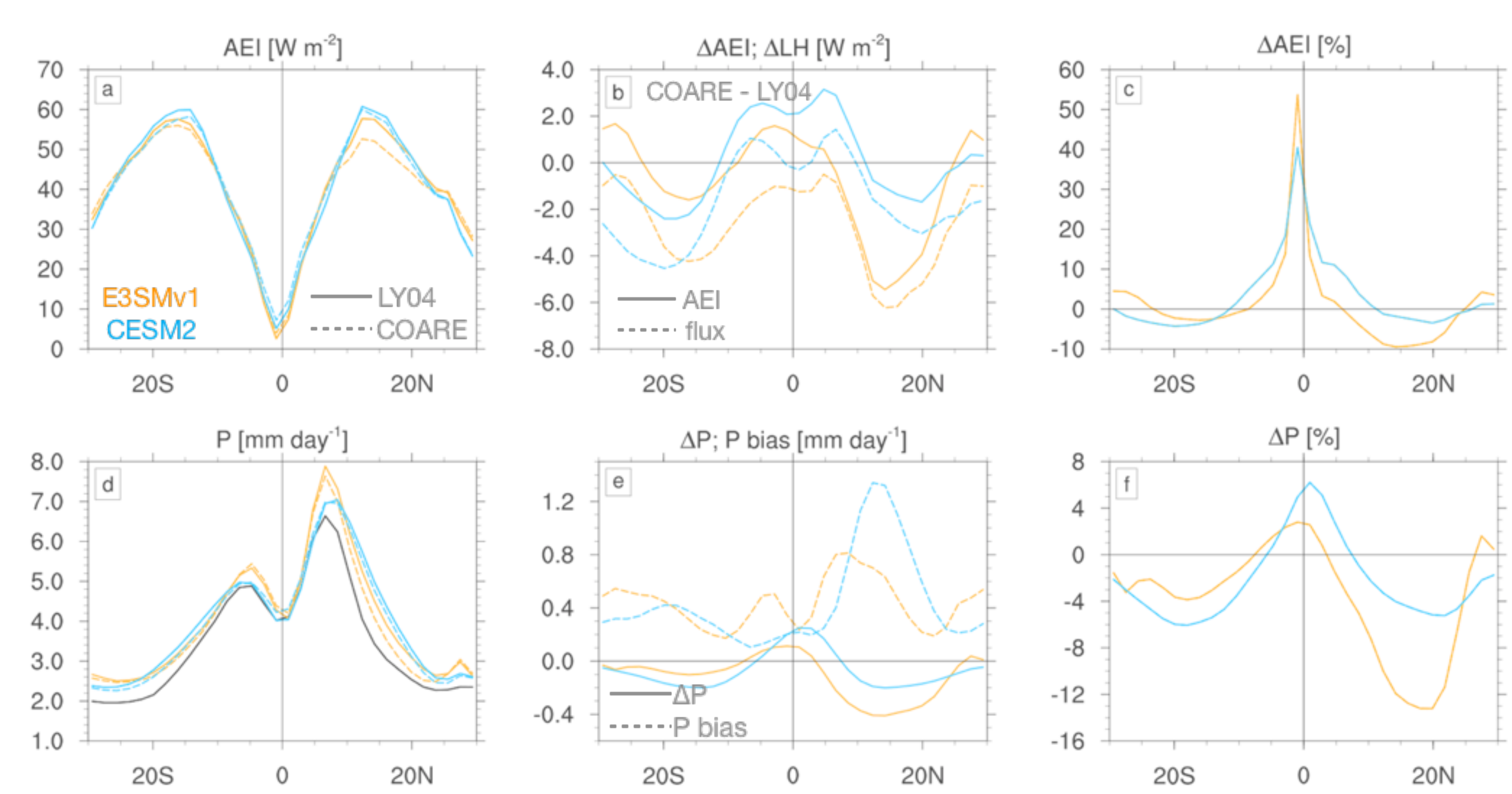


Fig. 5. a) Mean AEI zonally averaged for domain plotted in Fig. 4 using COARE3.0 and default (LY04) flux algorithms; b) AEI (solid) and LH (dashed) differences; c) as in b) but % differences. d-f) as in a-c) but for precipitation and except for TRMM climatology in black (d) and precipitation bias (dashed lines in panel e). E3SMv1 results by Reeves Eyre et al. 2021.

Next Steps

- Perform inline correction in coupled simulations
  - 10-year E3SMv1 coupled simulation completed
  - 20-year CESM2 coupled simulation planned
- CESM2 AMIP+4K simulation planned to estimate ECS with COARE3.0 fluxes (with input from Greg Cesana)
- Analysis of equatorially symmetric and anti-symmetric rainfall changes with COARE3.0 (with input from Aaron Donohoe)
- Analyze changes to mean state and variability for ocean and atmosphere in coupled simulations

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