Evaluating tropical cloud-circulation interactions in climate models

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1. Introduction

- Tropical cloud radiative effect and circulation are related (Bony et al 2004).
- Useful for evaluating models (Cronin & Wing, 2017; Walll & Hartmann, 2018) and understanding cloud feedback processes (e.g. Byrne & Schneider, 2018)
- Limited observational analysis of these relationships to date (Yuan et al, 2007).
- Many open questions about these relationships (e.g. temporal/spatial scales, ENSO phase, SST).
- Do climate models reproduce these relationships?
- Can we encode the information in these relationships in a simple function to facilitate quantitative analysis?

2. Data

- Focus on tropical Pacific (large area with minimal surface variability; Fig. 1)
- Radiation and cloud from CERES-EBAF satellite product.
- Vertical velocity from reanalyses (ERA5, JRA55, MERRA2).
- Evaluate AMIP (atmosphere only, observed SST and sea ice) models from CMIP6.

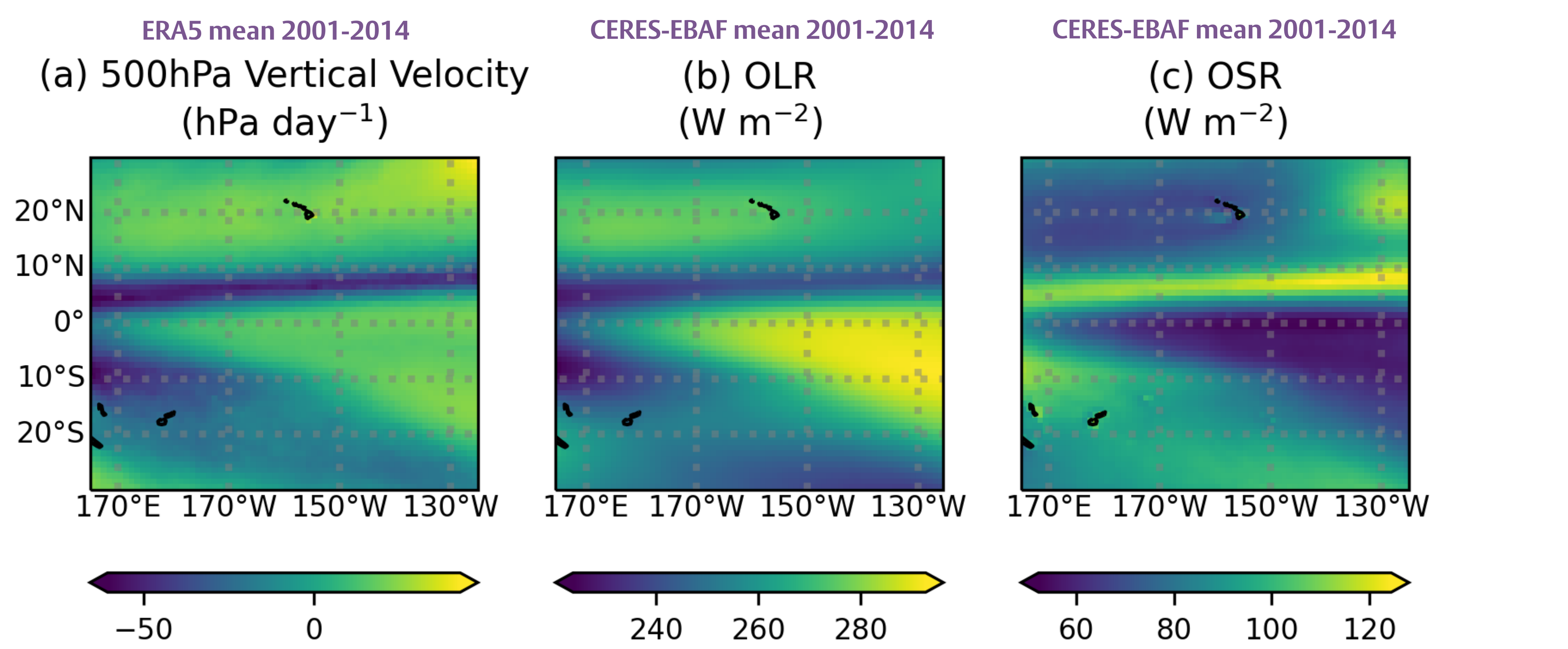

Figure 1. Mean (a) vertical velocity from ERA5, (b) top of atmosphere outgoing longwave radiation from CERES-EBAF, and (c) top of atmosphere outgoing shortwave radiation from CERES-EBAF for the tropical Pacific region used in this study.

3. Quantifying the relationship between clouds and circulation

- Simple fit to relationship with 4 parameters.
- Easy to interpret.
- Facilitates quantitative evaluation of models and analysis of impact of other variables on the ω500-CRE relationship.

$$\text{CRE} = \begin{cases} A - (A - B)e^{C(\omega - D)}, & \omega < D \\ B, & \omega \geq D \end{cases}$$

- A = asymptotic CRE for strong ascent
- B = CRE for descending regions
- C = related to rate of change of CRE with ω (but note gradient also depends on A,B)
- D = point where shape changes

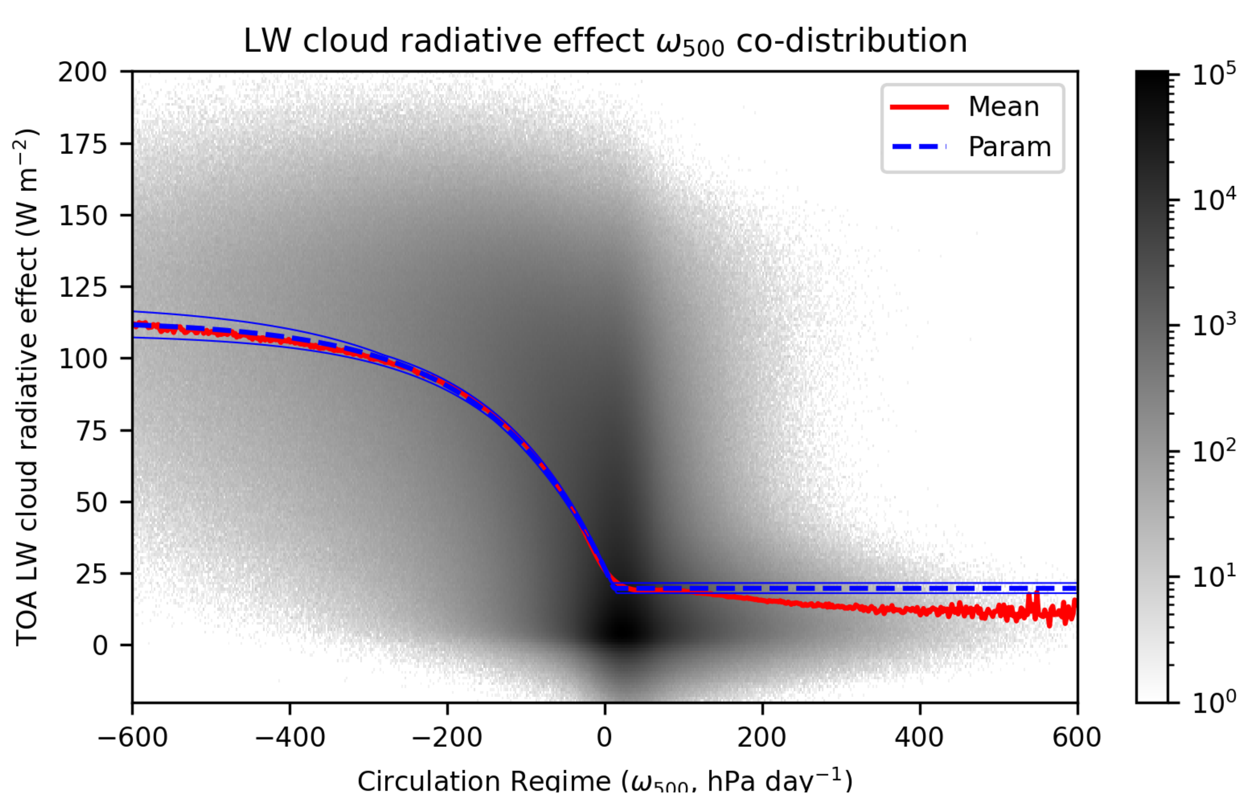

Figure 2. Example of fit for 1° daily scale data, for combination of top of atmosphere longwave cloud radiative effect from CERES-EBAF and vertical velocity from all three reanalyses.

Summary

- Fitting simple functions to the CRE-ω500 curves results in easily interpretable parameters that facilitate further analysis of the CRE-ω500 relationship
- Large variability in CRE-ω500 relationship amongst climate models. None within observational uncertainty for all parameters.
- Ongoing work – implications for tropical cloud feedbacks simulated by these models.

4. Cloud-circulation relationships in AMIP

- Most models have too strong a circulation (Fig. 1a; circulation intensity is mean absolute value of vertical velocity).
- Almost all models have most common (modal)) vertical velocity within uncertainty rang of observations (Fig. 1b).

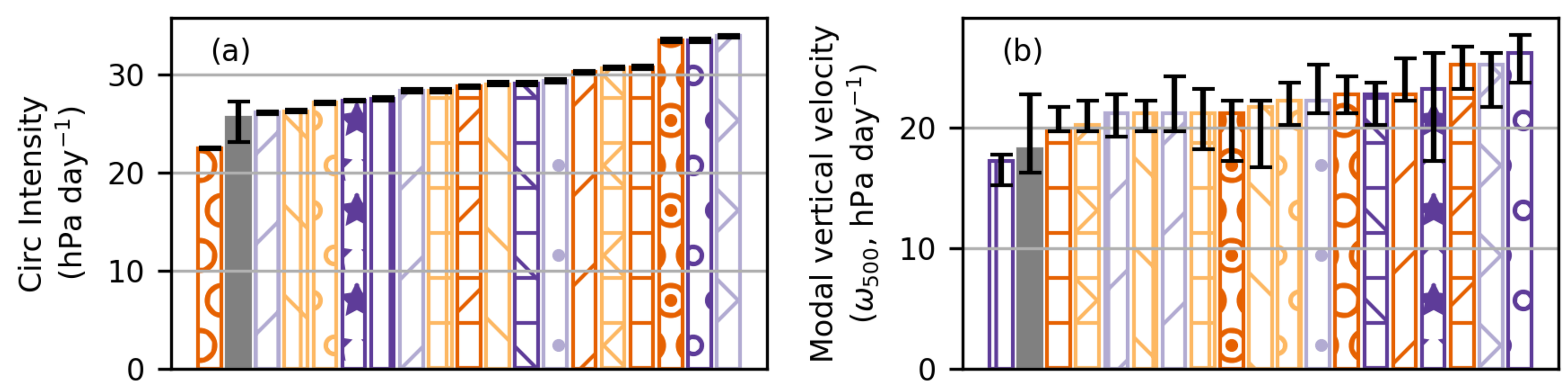

Figure 3. (a) Intensity of circulation (mean absolute value of 500 hPa vertical velocity). (b) Modal 500 hPa vertical velocity. Grey solid filled bar corresponds to average of results from three reanalyses, coloured bars correspond to AMIP models as denoted by legend in Figure 4.

- Fit performs well for all AMIP models, with RMS error only a fraction larger than that for mean of data (Fig. 4e).
- AMIP parameters for ascending regions are generally within observational uncertainty (Fig. 4a,c), but most models underestimate CRE in descending regions (Fig. 4b)

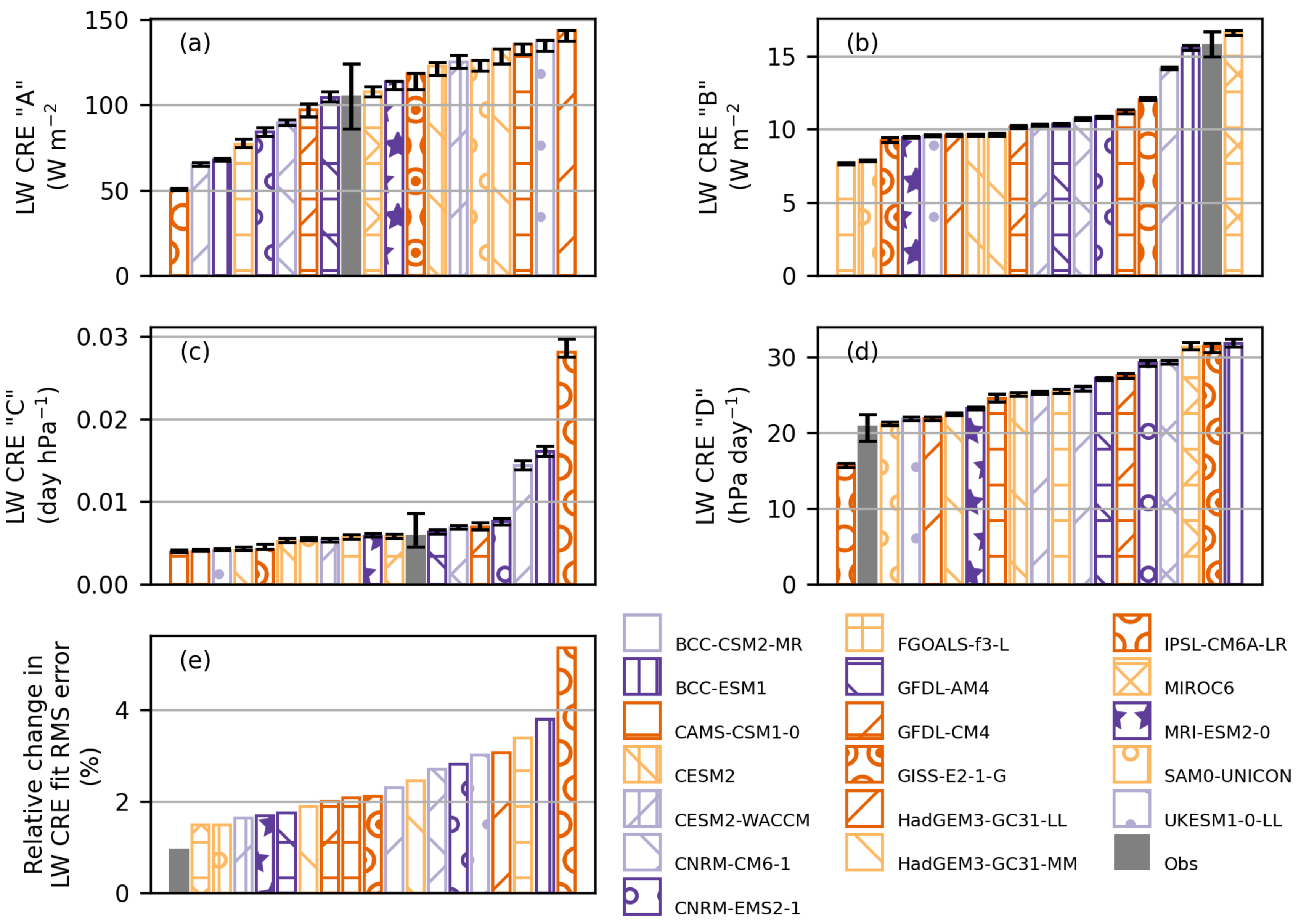

Figure 4. (a-d) Parameters defined in section 3, estimated by minimising least square errors. (e) shows the increase in RMS error for each fit for each dataset, relative to the RMS error for the mean for that dataset.

References

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