What's wrong with microphysics in global models?

Johannes Mülmenstädt and many collaborators

Pacific Northwest National Laboratory

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Why I am optimistic about climate projections: progress is possible!

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COMMENTARY

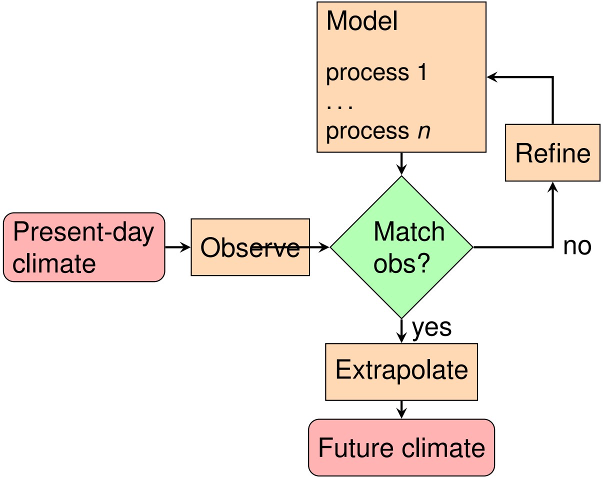
10.1029/2021MS002781

The Fall and Rise of the Global Climate Model

Johannes Mülmenstädt[1] and Laura J. Wilcox[2,3]

Terai et al. (2020); Mülmenstädt and Wilcox (2021)

If nature were kind, we could follow this flow chart

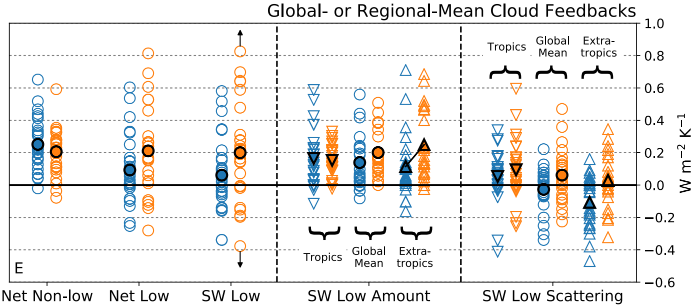


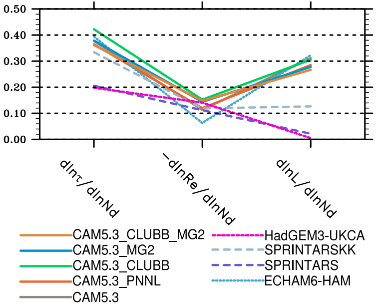
This approach has not worked so far because we have run into problems:

- Observations both underconstrain and overconstrain the model
- Observations of PD state do not constrain the sensitivity to perturbations
- Observations mean something different than the corresponding model field

Too many parameter combinations are consistent with observed state
Parameter combinations resulting in good process representation yield bad climate

These models are all tuned to the present day

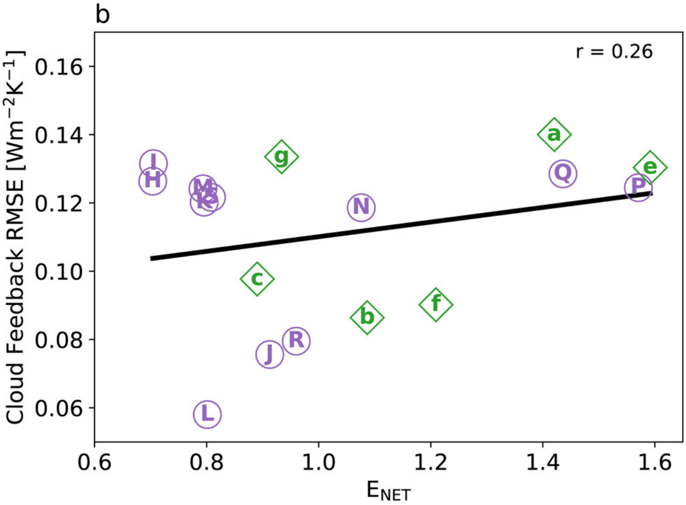




... but the spread in climate projections is large

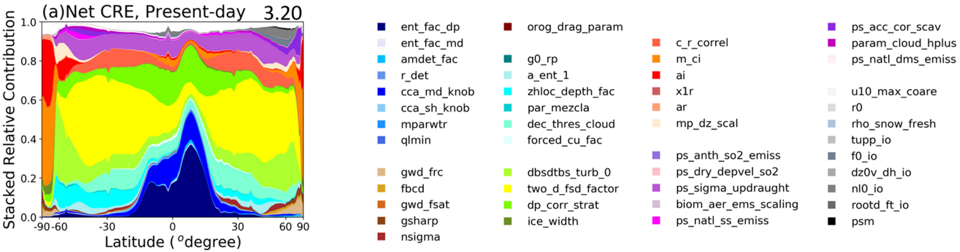
Zelinka et al. (2020); Ghan et al. (2016)

Cloud state is a “necessary but insufficient” constraint on feedback



Zelinka et al. (2022)

State and sensitivity



Tsushima et al. (2020); Regayre et al. (2018); Lee et al. (2016); von Bertalanffy (1950)

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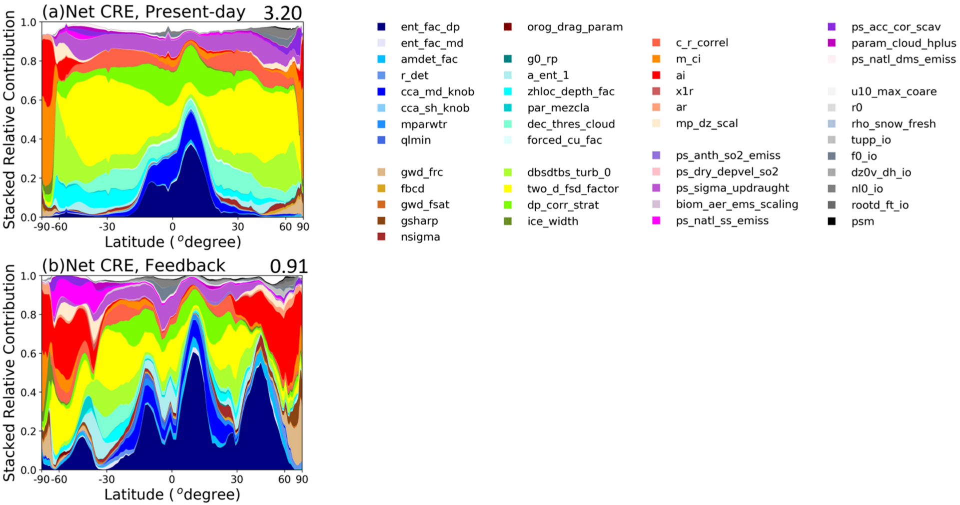

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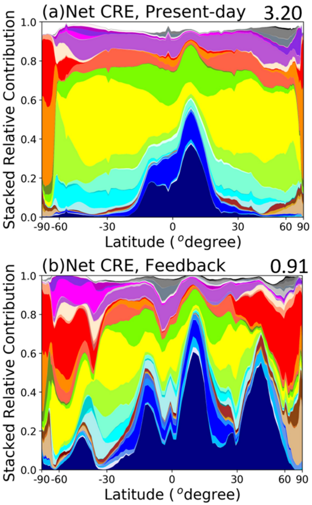
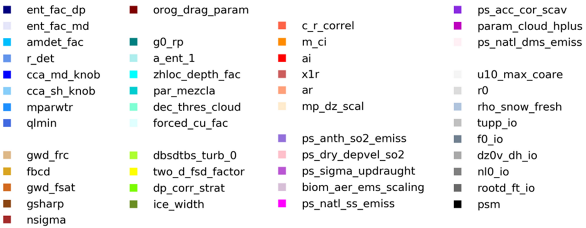
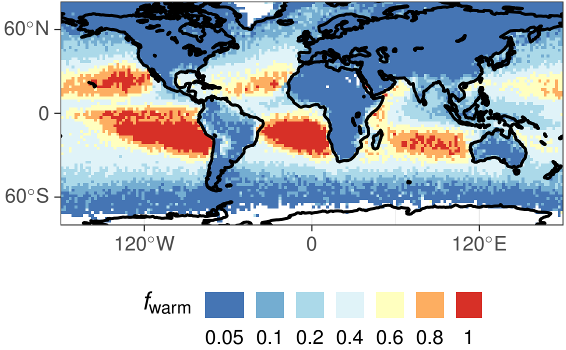




1. Cloud state and cloud feedbacks are fundamentally controlled by different model parameters
2. Models are a tangle of compensating process errors can be combined in different ways to give a similar state, but all have different sensitivities to perturbations – equifinality
3. Constraining cloud state (e.g., CRE, SLF) is likely not enough to constrain the feedback

Tsushima et al. (2020); Regayre et al. (2018); Lee et al. (2016); von Bertalanffy (1950)

What process observations/understanding are available?



Warm rain and cloud-top entrainment not only control ACI adjustments and cloud feedback but are a microcosm of equifinality

Mülmenstädt et al. (2015, 2021)

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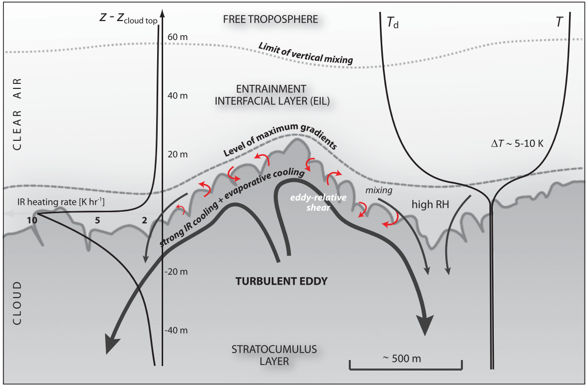
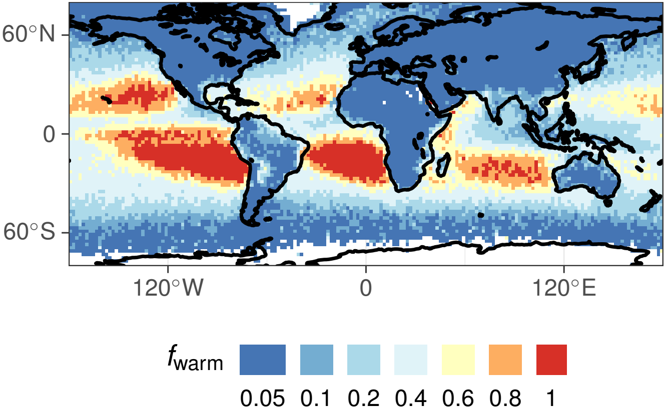


Warm rain and cloud-top entrainment not only control ACI adjustments and cloud feedback but are a microcosm of equifinality

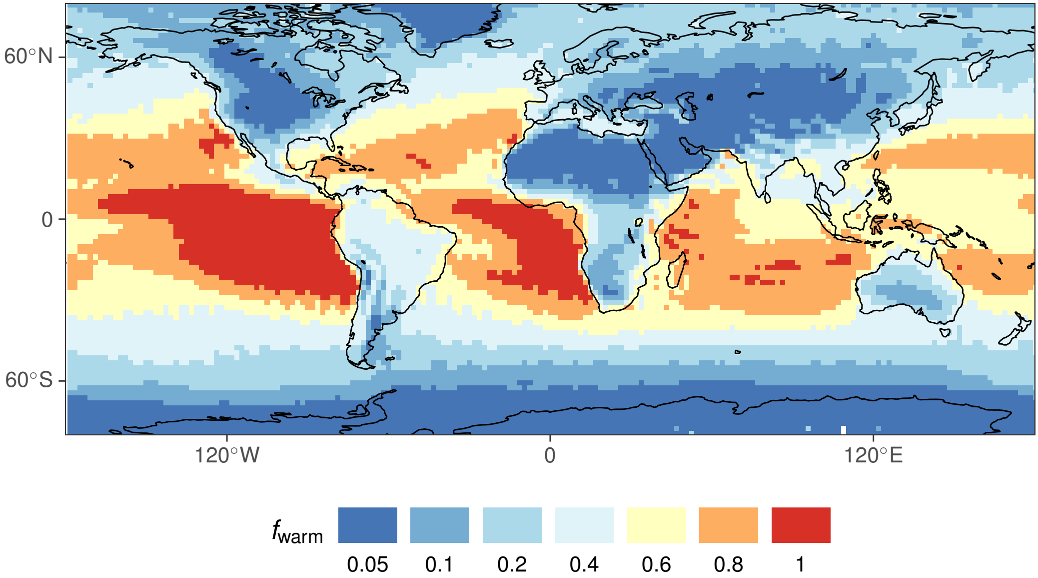
Wood (2012)

Warm rain is very rare over land and over the extratropical oceans

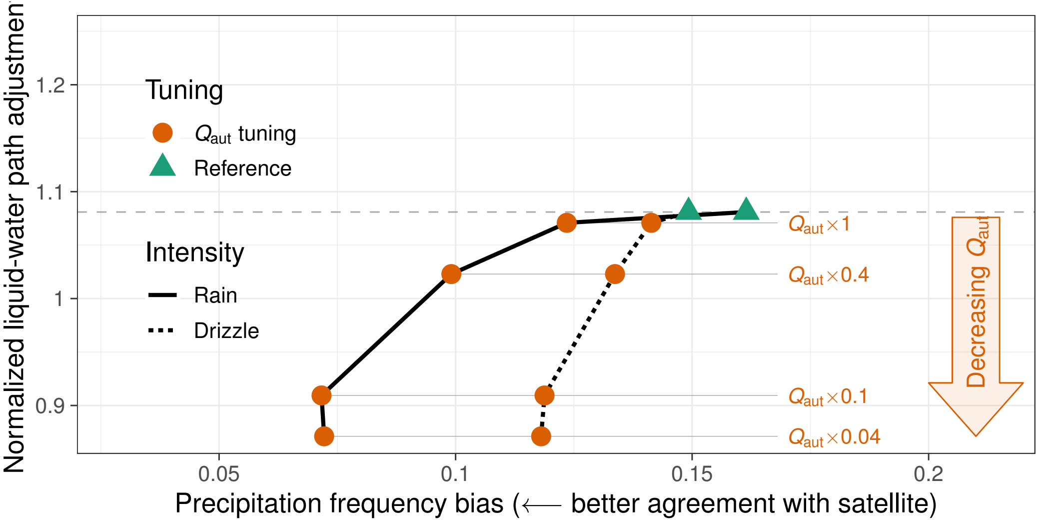


Mülmenstädt et al. (2015); see also Field and Heymsfield (2015)

But not in GCMs!

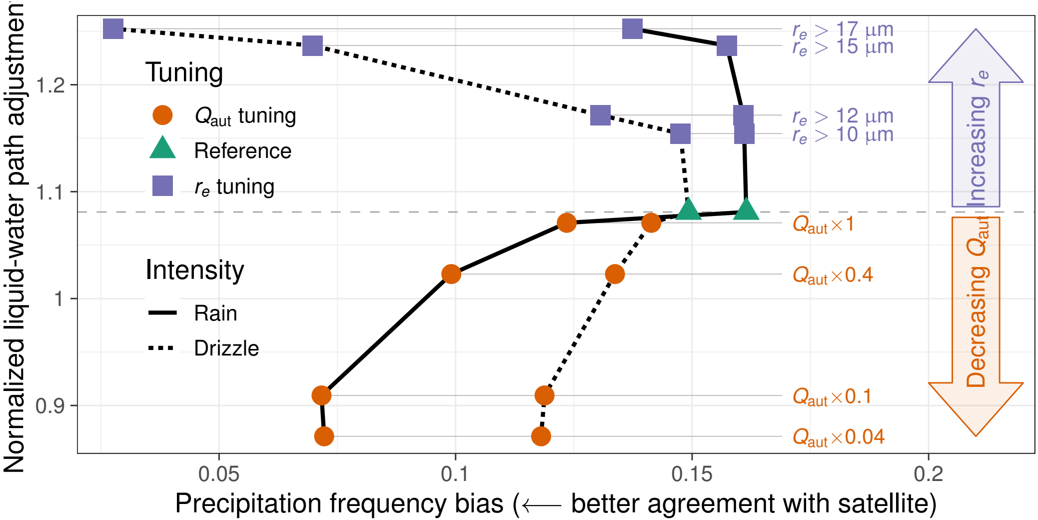


Warm rain has a large effect on ACI adjustments . . .



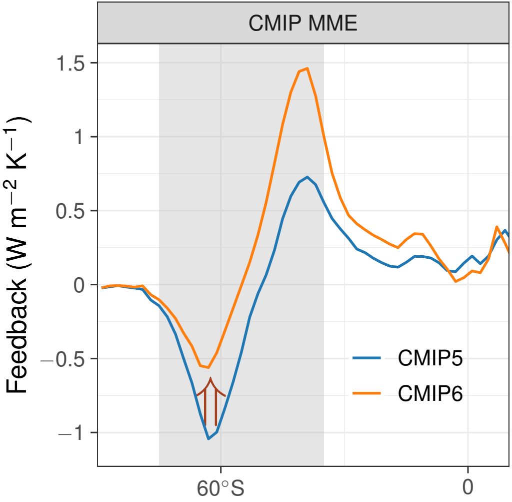
Mülmenstädt et al. (2020)

. . . but we don't even know which direction to correct in



Mülmenstädt et al. (2020)

Warm rain has a large effect on extratropical phase feedback . . .



Zelinka et al. (2020)

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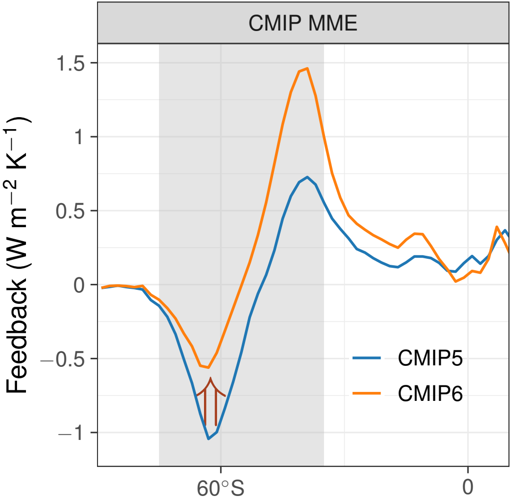
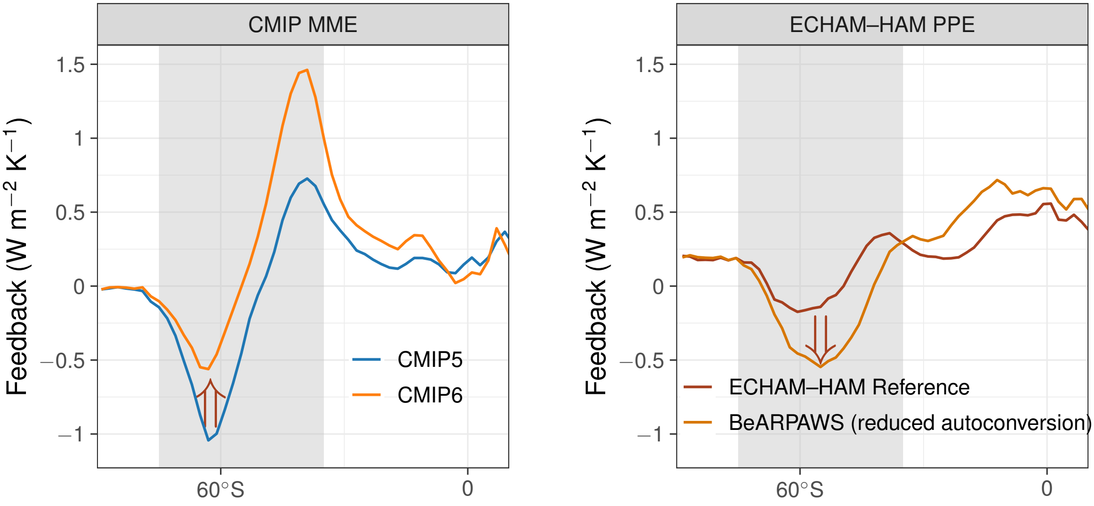


Zelinka et al. (2020)

- What is the effect of overestimating warm rain efficiency?
- Decrease in sink efficiency is underestimated as warm clouds replace cold clouds
- Therefore, negative cloud feedback strength is underestimated

Warm rain has a large effect on extratropical phase feedback . . .



Zelinka et al. (2020); Mülmenstädt et al. (2021)

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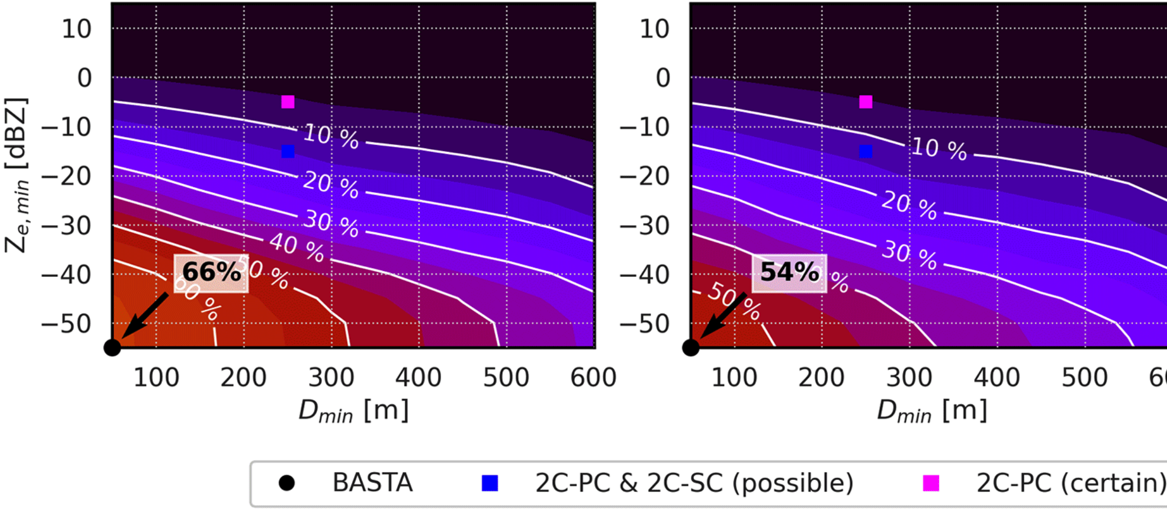
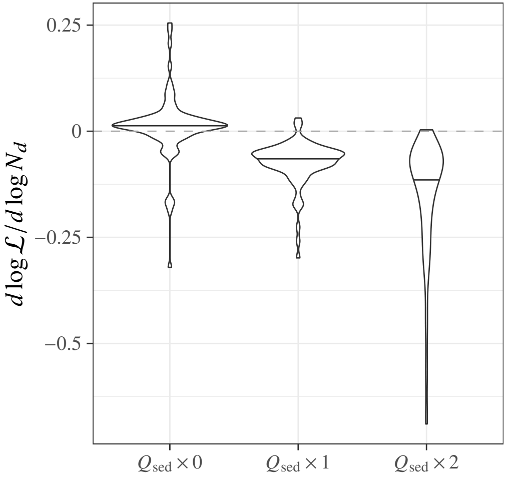


Stanford et al. (2023)

Entrainment should have a large effect on ACI adjustments . . .



Mülmenstädt et al. (2024), consistent with Karset et al. (2020)

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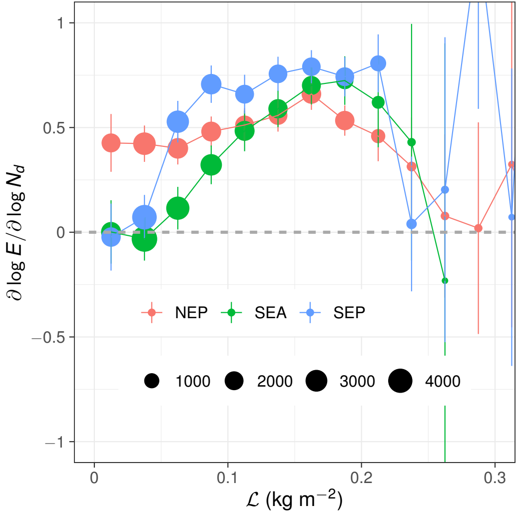
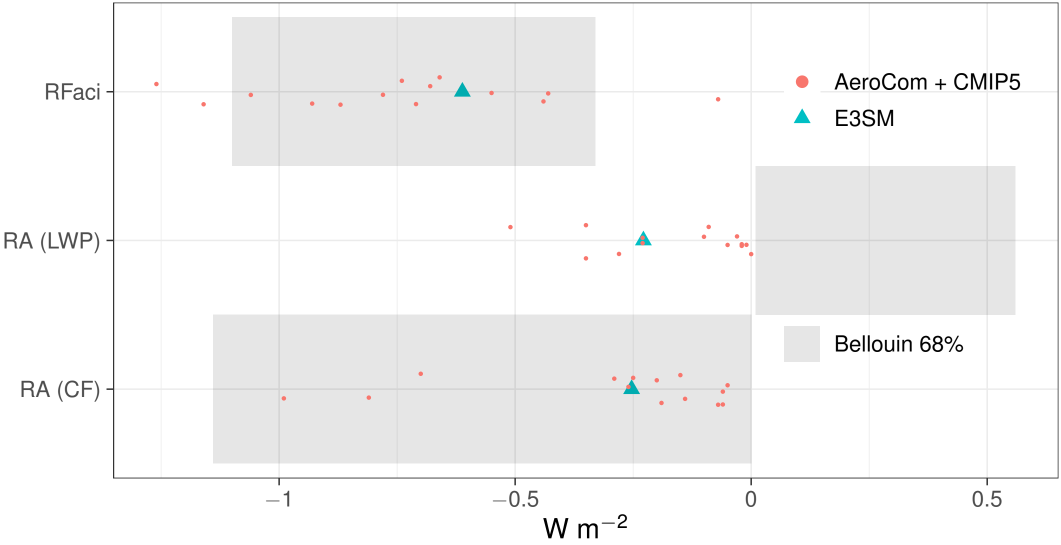


Mülmenstädt et al. (2024), consistent with Karset et al. (2020)

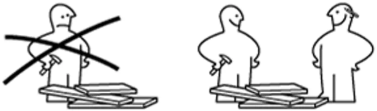
. . . but its actual effect is zero



Bellouin et al. (2020); Gryspeerdt et al. (2020)

What’s wrong with microphysics in global models?

What's wrong with ~~microphysics in global models?~~ us?



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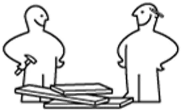

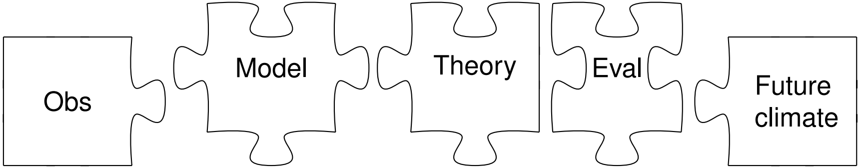

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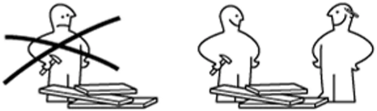

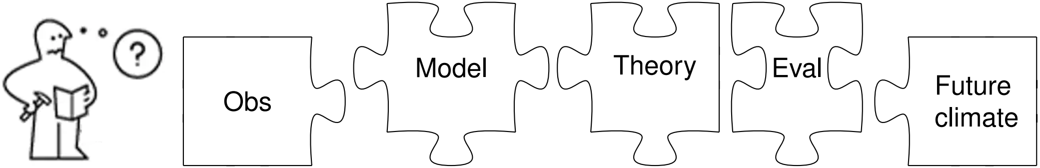

What would we find if we tried to put all the puzzle pieces together?

What fundamental uncertainties are we wombating?

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Can we predict emergent properties of one complex system (climate) using a structurally different second complex system (climate model)?

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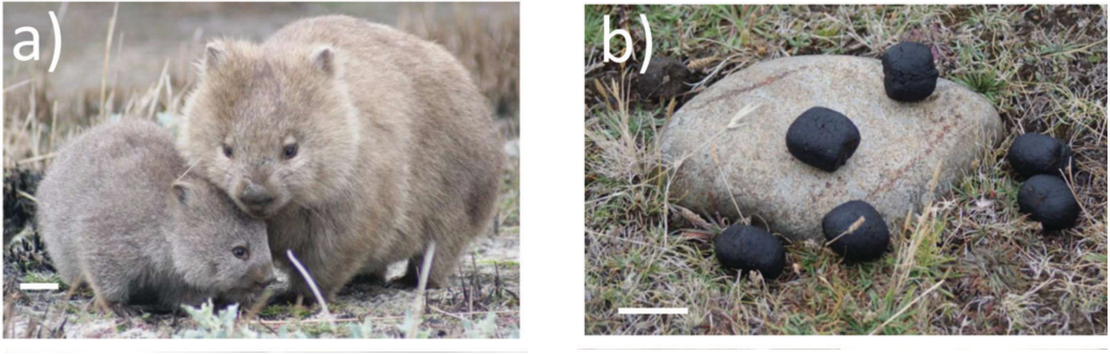
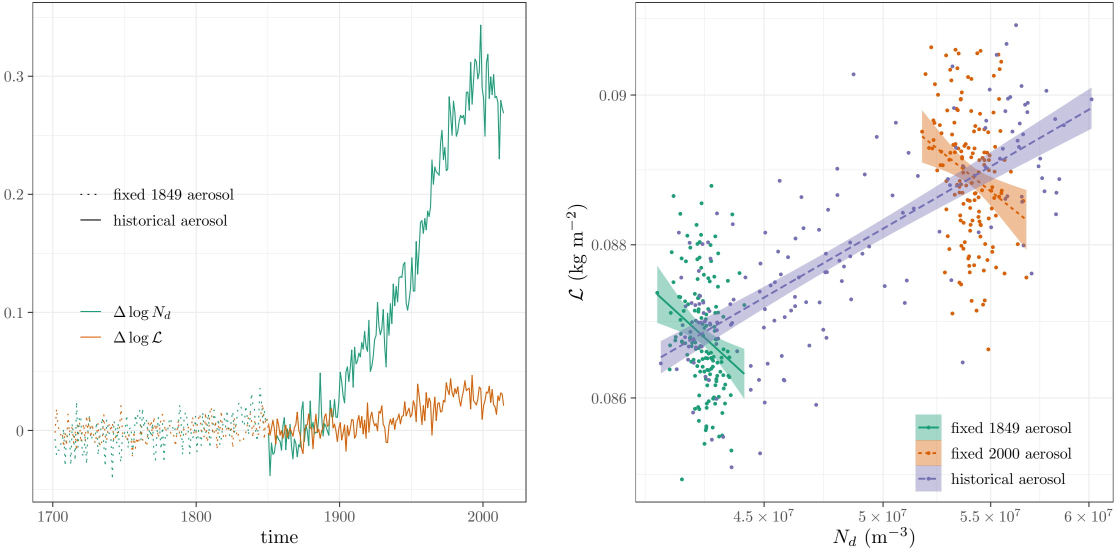
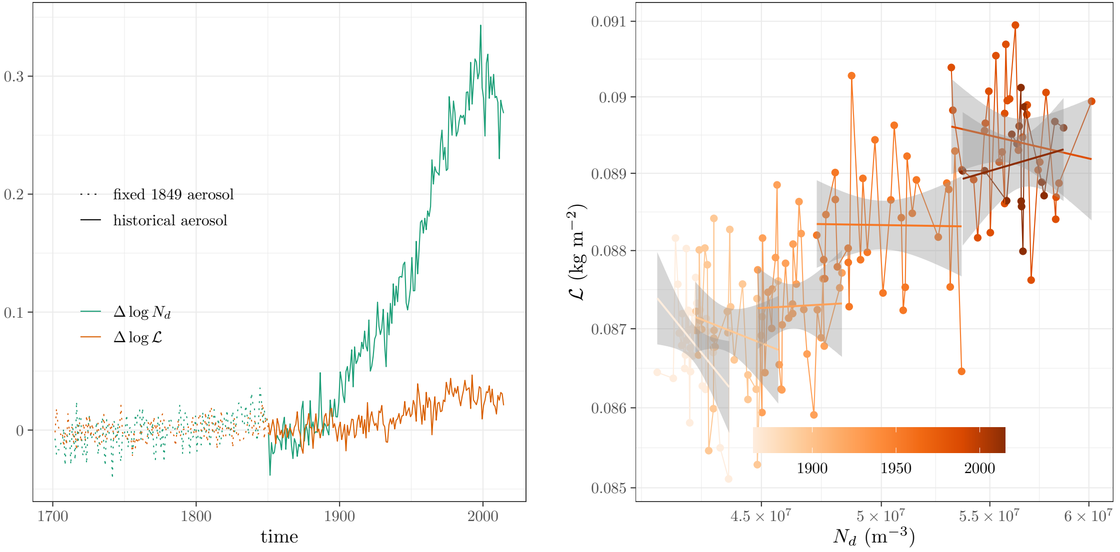


Can we predict emergent properties of one complex system (climate) using a structurally different second complex system (climate model)?

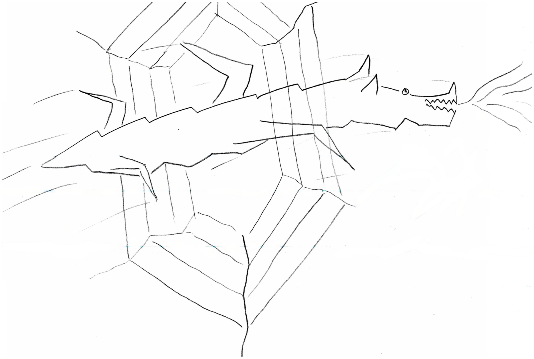
Internal variability can only tell us so much about the forced response



Even 30-year slices are unreliable estimators of the forced response



Weave lines of evidence into a tight net for this multiscale problem



Mülmenstädt et al. (2024)

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Atmospheric Chemistry and Physics
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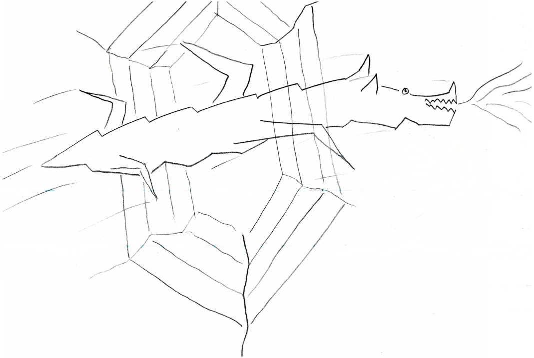
Research article

General circulation models simulate negative liquid water path–droplet number correlations, but anthropogenic aerosols still increase simulated liquid water path

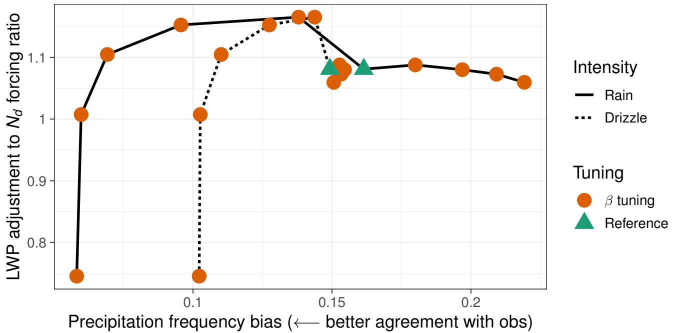
Johannes Mülmenstädt[1], Edward Gryspeerdt[2], Sudhakar Dipu[3], Johannes Quaas[3], Andrew S. Ackerman[4], Ann M. Fridlind[4], Florian Tornow[5,4], Susanne E. Bauer[4], Andrew Gettelman[1], Yi Ming[6], Youtong Zheng[7,8], Po-Lun Ma[1], Hailong Wang[1], Kai Zhang[1], Matthew W. Christensen[1], Adam C. Varble[1], L. Ruby Leung[1], Xiaohong Liu[9], David Neubauer[10], Daniel G. Partridge[11], Philip Stier[12], and Toshihiko Takemura[13]



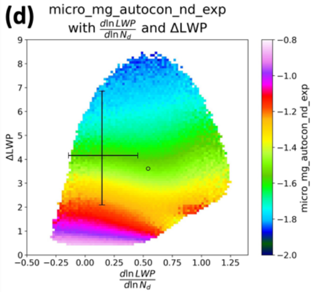
Mülmenstädt et al. (2024)

Mind the base state!

(Feeble) attempt to account for base state change



No attempt to account for base state change



Climate response depends on base state, the Achilles heel of model physics studies

PPEs offer a way to solve this problem cleanly: only look at the hyperslice through parameter space that respects present-day constraint (CPE, see Elsaesser et al.)

Mülmenstädt et al. (2020); Mikkelsen et al. (2024)

Why I am optimistic about climate projections:

- Things look pretty bleak right now, but it is in our power to make them better

Why I am optimistic about climate projections:

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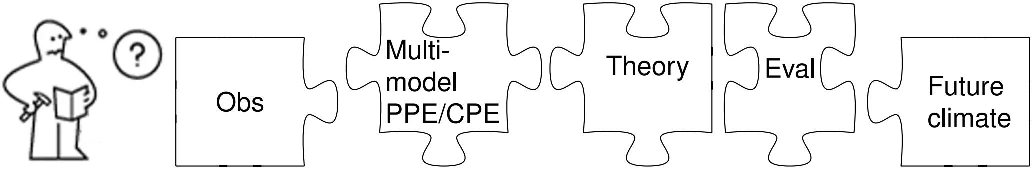
- Key ingredients: MMPPEs to tell us what the climate is sensitive to, observations designed from the outset to constrain those processes



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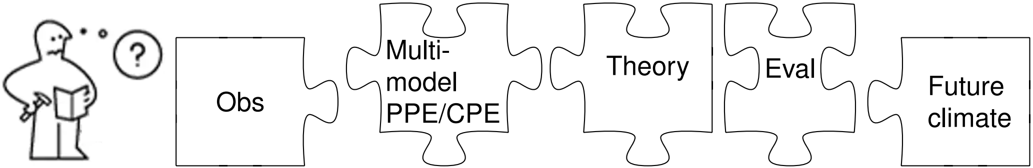

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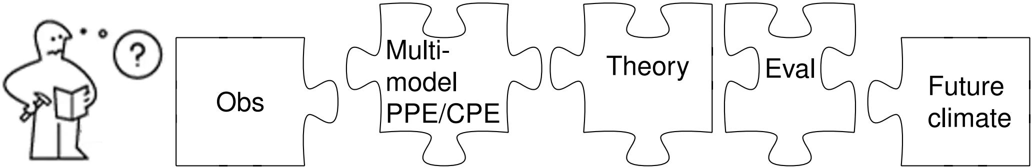
- Key ingredients: MMPPEs to tell us what the climate is sensitive to, observations designed from the outset to constrain those processes
- Don't do more than is possible – but don't do less, either!



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