Disentangling model structural and parametric causes of uncertainty

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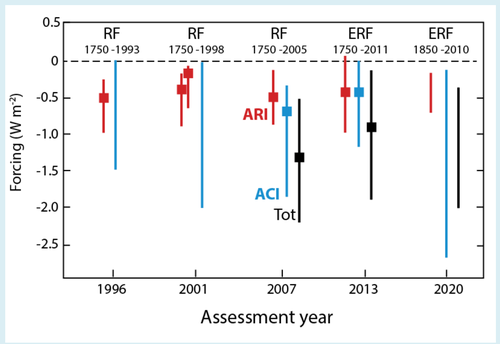
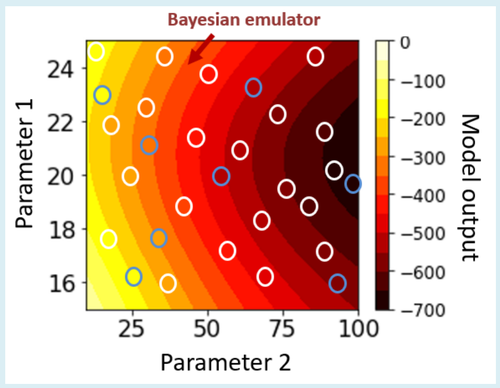
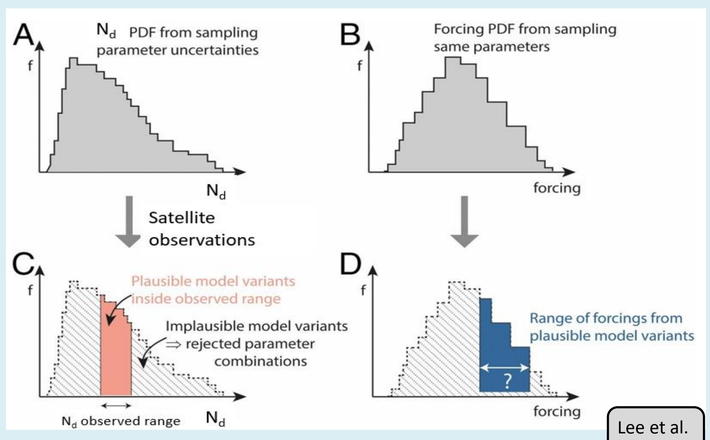
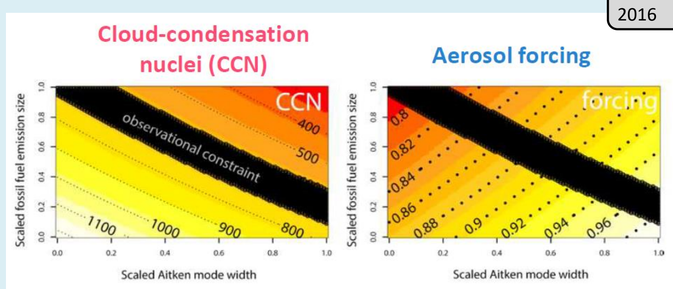
1. Our approach to constraining aerosol-cloud interaction forcing (ΔF_{aci})







Lee et al. 2016

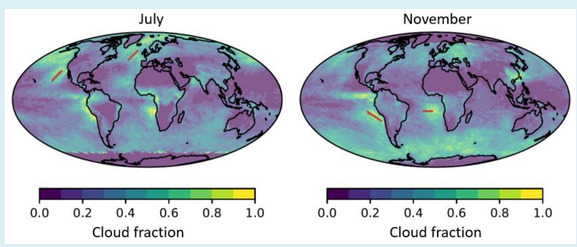


A perturbed parameter ensemble (221 members) and Bayesian emulation (1 million model variants) allow us to 1) quantify model parametric uncertainty, 2) challenge model variants with satellite data, 3) identify structural model inadequacies, and 4) characterize process-based limits to ΔF_{aci} constraint

2. Satellite-derived observational constraints

More than 450 satellite-based observations in 5 regions used to challenge 1M model variants:

- Transects from St. to Cu. regions
- Monthly and annual mean, and seasonal amplitude of state variables
- Hemispheric difference in cloud drop concentrations (H_d)

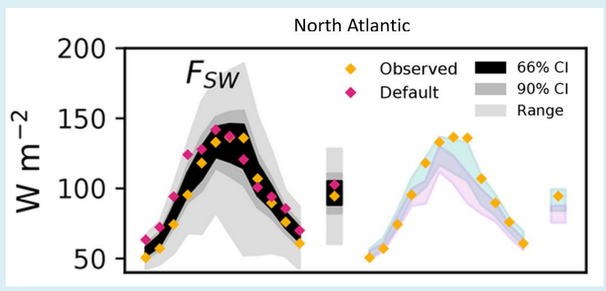


Region	Latitude range	Longitude range
North Atlantic	34.4° to 54.4° N	329.1° to 347.8° E
North Pacific	14.4° to 48.1° N	197.8° to 231.6° E
South Atlantic	30.6° to 10.6° S	347.8° to 2.8° E
South Pacific	30.6° to 15.6° S	254.1° to 284.1° E
Southern Ocean	30.6° to 50.6° S	0° to 360° E

H_d : Hemispheric N_d contrast
T: Sc. to Cu. transects (e.g., dN_d/dLWP)
F_{SW}: SW flux
F_c: cloud fraction
N_d: Droplet number
r_e: Effective radius
τ_c: Optical depth
LWP: Liquid water path

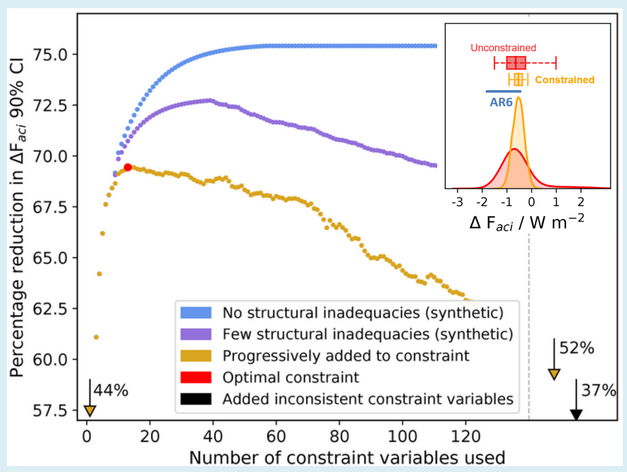
Regayre et al. 2023

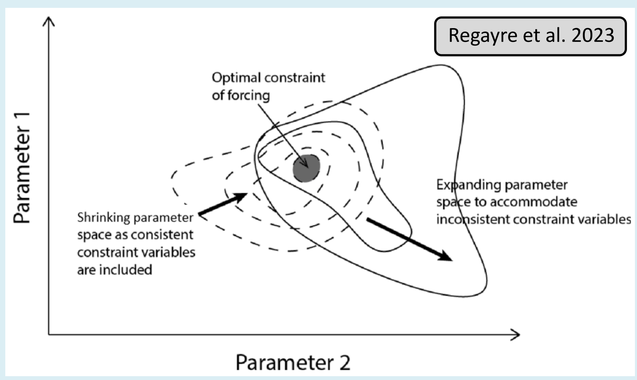
3. Exposing the problem of inconsistent constraint effects



Tight constraint to observed N_d (green) is consistent with observed F_{SW} in all months
Constraint to LWP (pink) is inconsistent - model F_{SW} errors increase after LWP constraint

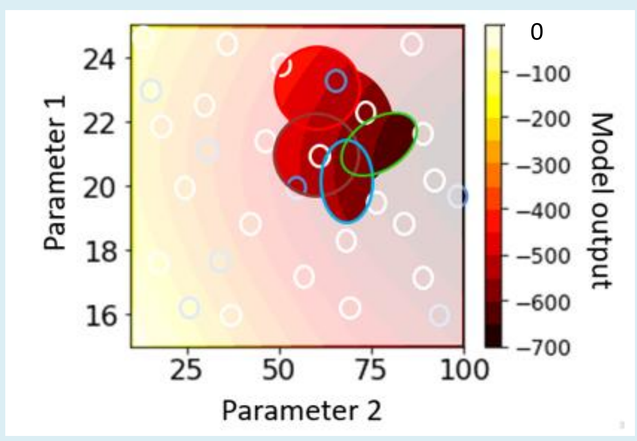
The tightest ΔF_{aci} constraint ('optimal') needs only 13 observation types, associated with internally consistent model variables

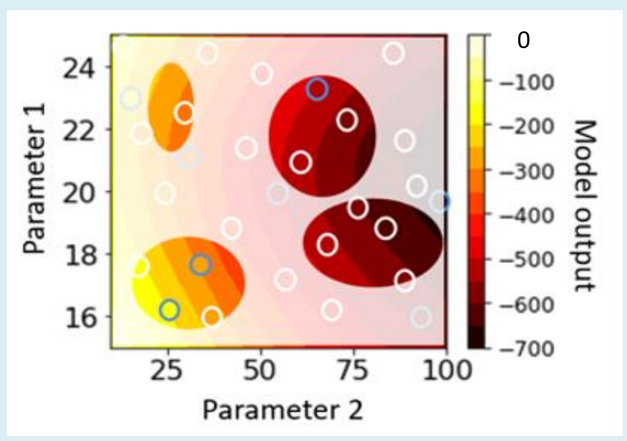




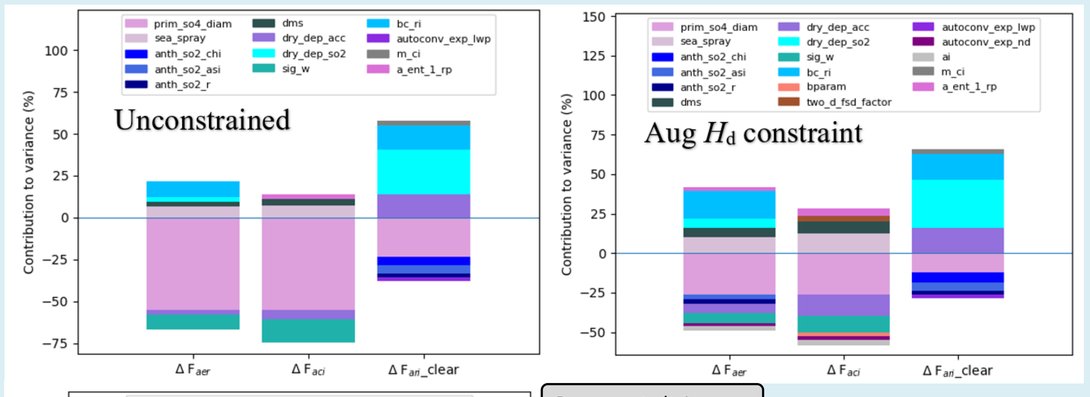
Adding further observations demands compromise that reduces the impact of constraint on parameter combinations and weakens ΔF_{aci} constraint

More observations could be used for constraint if we had a model free of structural errors





4. Effects of constraint on remaining forcing uncertainty



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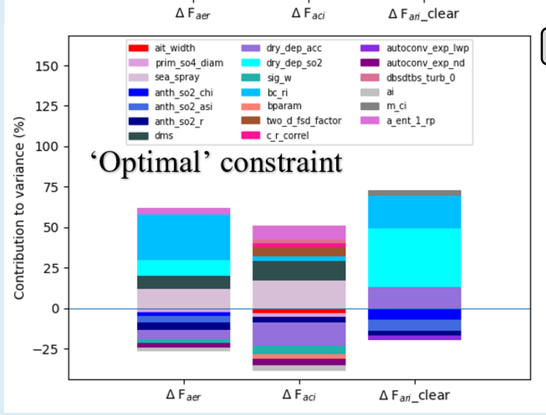
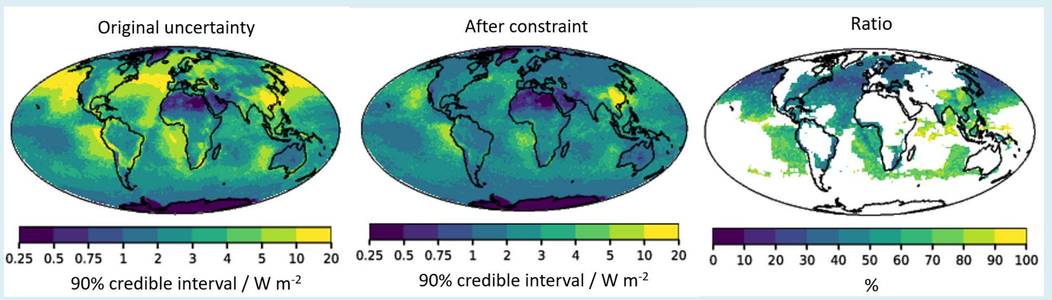


Causes of remaining ΔF_{aci} uncertainty evolve as constraints are added (as some parameters cause less, others cause more)

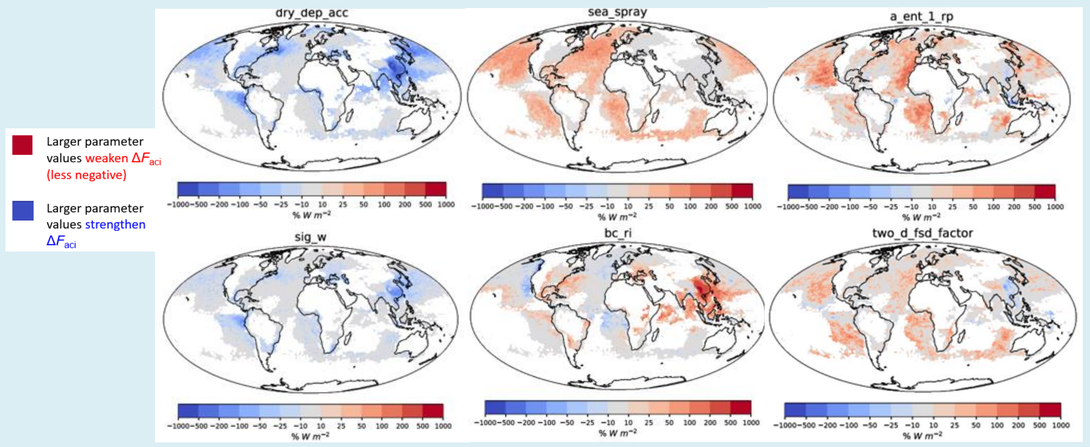
Parameters that cause remaining uncertainty after optimal constraint inform **how to further constrain ΔF_{aci}**

5. Mapping the causes of remaining uncertainty

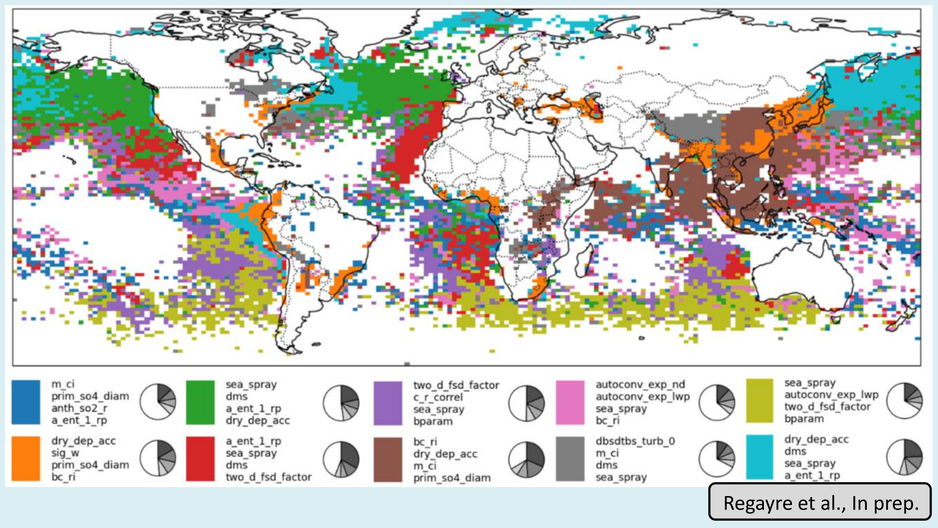
Uncertainty is reduced almost everywhere, with the greatest proportional reduction in N. Hemisphere marine regions. Yet, remaining uncertainty is widespread.



The spatial footprint of causes of remaining ΔF_{aci} uncertainty is unique for all 37 model parameters – potential for further constraint partially limited by equifinality



Clusters of model behaviour defined according to combined parametric causes of *remaining* ΔF_{aci} uncertainty after constraint. Useful to **group observations for additional ΔF_{aci} constraint** (as opposed to using regional means)



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6. Key results

Constraint is stronger when we account for model structural inconsistencies.
We know which parameters cause the remaining ΔF_{aci} uncertainty
Additional constraint could be achieved through:

- **model developments that target structural inconsistencies**
- **Use of observations within clusters (targeting parameter combinations)**
- **Process-based observational constraints (St. to Cu. transitions)**