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Decomposing the aerosol radiative forcing in global models

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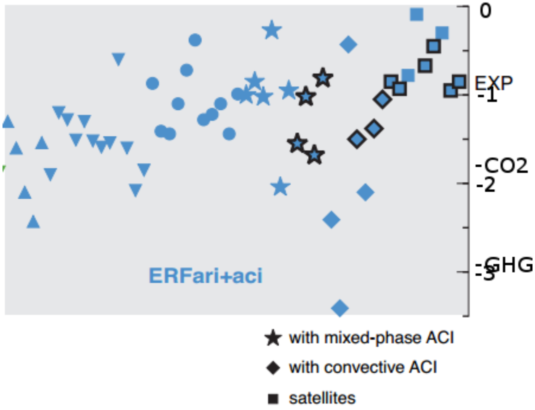
25th September 2019

The aerosol radiative forcing



- Modelled and observational estimates do not agree

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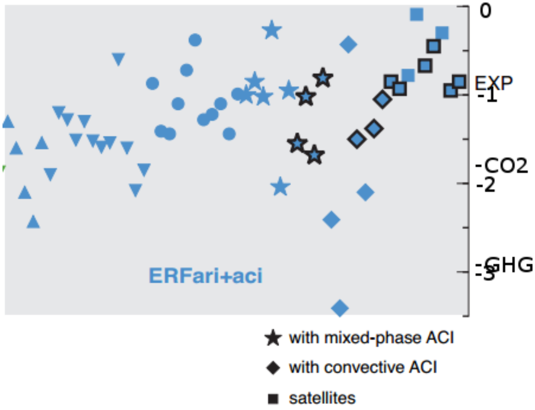

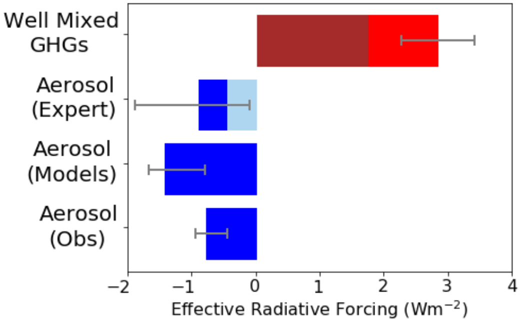

- Modelled and observational estimates do not agree
- Observational estimates are more highly weighted

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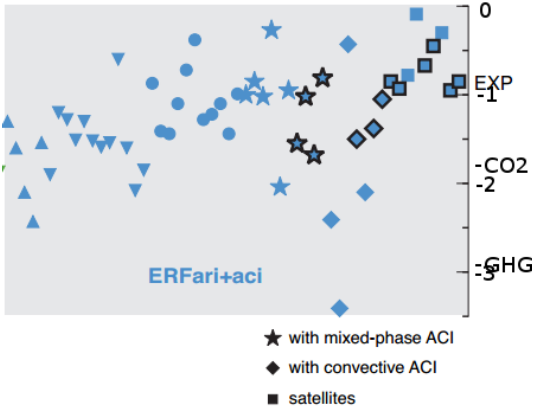
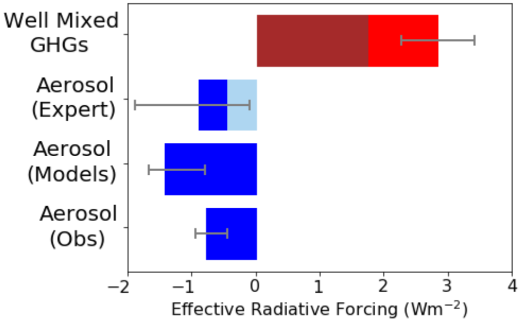


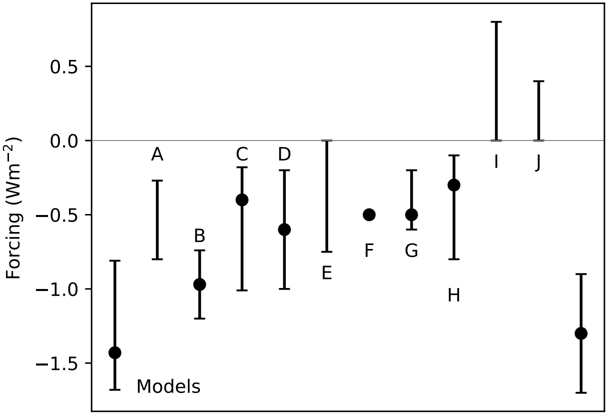


- Modelled and observational estimates do not agree
- Observational estimates are more highly weighted
- How can we best compare models and obs?

Observational estimates

Aerosols may impact

- Droplet number N_d (Twomey/RFaci)
- Liquid water path (LWP)
- Cloud fraction (CF)



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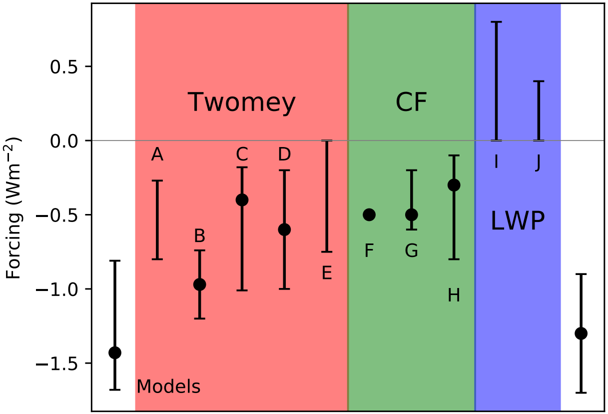

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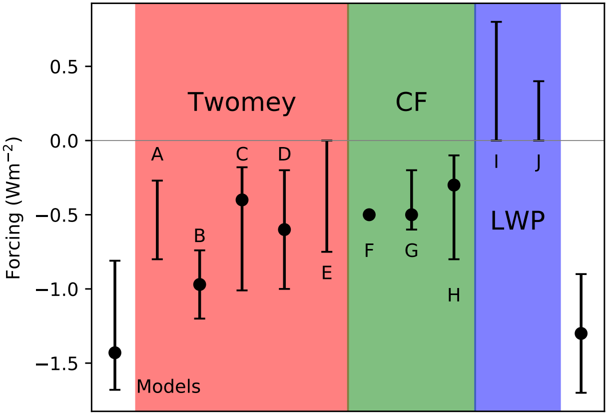
Estimating components in models is expensive:

- Many radiation calls (e.g. double call, PRP)
- Four PD-PI pairs required for liquid cloud adjustments



Apple to oranges?

Apple to oranges?

Decomposing the forcing

Aim to decompose a single PD-PI pair into the forcing components

- Δ - PD-PI change
- f_c - total cloud fraction
- α^{NoA} - albedo with aerosol optical depth=0

Residual from decomposition less than 5% in SW

$$
\begin{aligned}
\Delta SW \approx F^{\downarrow}((1-f_c)\Delta\alpha_{clr}^{NoA} & \quad \text{Surf.} \\
+(1-f_c)\Delta(\alpha_{clr}-\alpha_{clr}^{NoA}) & \quad \text{SWari}_{cs} \\
+f_c\Delta(\alpha_c-\alpha_c^{NoA}) & \quad \text{SWari}_{cld} \\
+f_c\Delta(\alpha_c^{NoA}) & \quad \text{SW}_{alb} \\
+(\alpha_c-\alpha_{clr})\Delta f_c) & \quad \text{SW}_{cf}
\end{aligned}
\tag{1}
$$

$$
\begin{aligned}
\Delta LW \approx (1-f_c)\Delta OLR_{clr} & \quad \text{LWari}_{cs} \\
+f_c\Delta OLR_c & \quad \text{LW}_{c} \\
+(OLR_c-OLR_{clr})\Delta f_c & \quad \text{LW}_{cf}
\end{aligned}
$$

Separating liquid cloud adjustments

Two further assumptions:

1. Changes can be decomposed to liquid and ice changes

$$f_c \Delta\alpha_c = f_l \Delta\alpha_l + f_i \Delta\alpha_i \qquad (2)$$

(4)

α_c - cloud albedo; α_l - liquid cloud albedo; $\Delta\alpha_l^{N_d}$ - change in cloud albedo at const. LWP

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2. LWP is leading control on cloud albedo

$$f_c \Delta\alpha_c = f_l \Delta\alpha_l + f_i \Delta\alpha_i \qquad (2)$$

$$\Delta\alpha_l^{LWP} = \left.\frac{d\alpha_l}{dLWP}\right|_{PD} \Delta LWP \qquad (3)$$

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Twomey effect is the residual

$$\Delta \alpha_l^{N_d} = \Delta \alpha_l - \Delta \alpha_l^{LWP} \quad (4)$$

α_c - cloud albedo; α_l - liquid cloud albedo; $\Delta \alpha_l^{N_d}$ - change in cloud albedo at const. LWP

Ice clouds...

Ice clouds change due to aerosol (overlapping liquid cloud)

- Observational studies assume that they don't
- Adjust the change in liquid CF accordingly

$$\text{Adjusted}\Delta f_l = \Delta f_l + \Delta f_i \frac{f_l}{1 - f_i} \tag{5}$$

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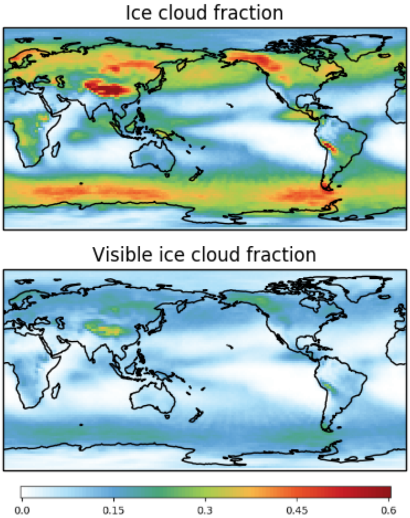
$$\text{Adjusted}\Delta f_l = \Delta f_l + \Delta f_i \frac{f_l}{1 - f_i} \quad (5)$$

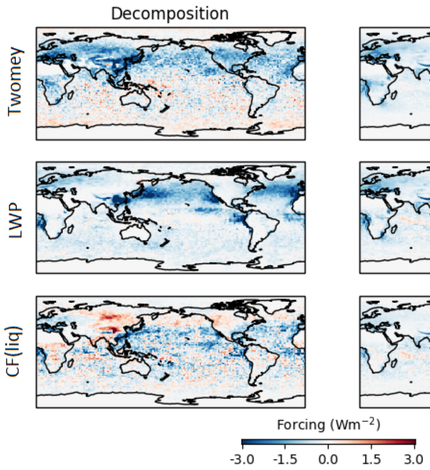
Observational studies cannot see thin ice clouds

- Assume thin ice clouds make a small contribution (in SW)

This can add -0.4Wm^{-2} to the overall liquid cloud forcing (model dependent)



Validation



Comparison of methods using ECHAM6-HAM:

	Twomey	LWP	CF_{liq}
PRP	-0.52	-0.57	-0.35

For PRP method see Mülmenstädt et al, ACPD, 2019

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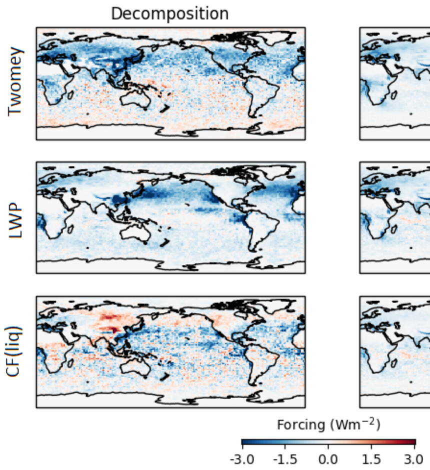

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- Similar component values to PRP method

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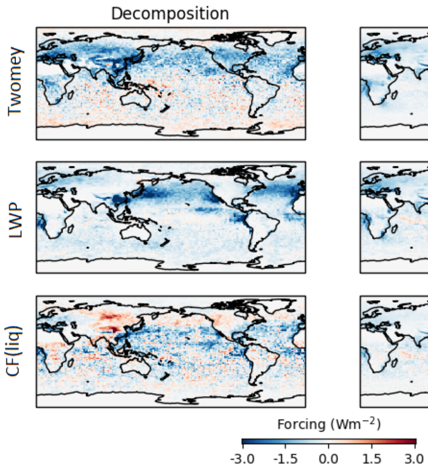


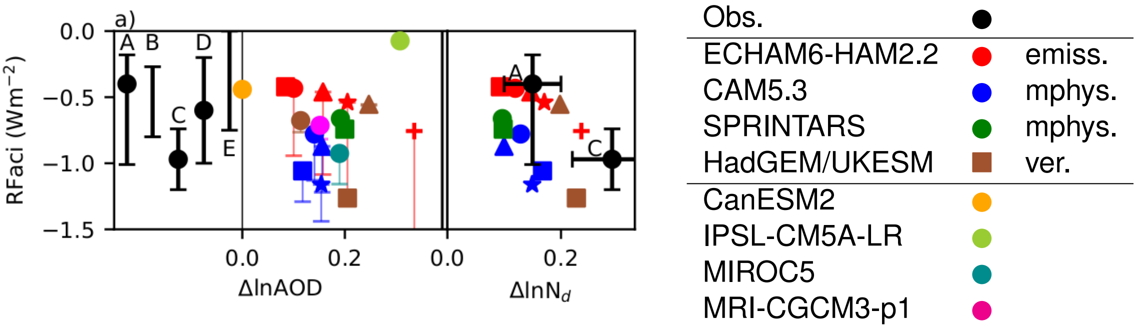
Comparison of methods using ECHAM6-HAM:

	Twomey	LWP	CF_{liq}
PRP	-0.52	-0.57	-0.35
Base	-0.43	-0.52	-0.29
CND	-0.42	-0.02	0.07

- Similar component values to PRP method
- Twomey similar to run with no cloud adjustments (CND)

For PRP method see Mülmenstädt et al, ACPD, 2019

The Twomey effect (RFaci)



Gryspeerdt et al., ACPD, 2019

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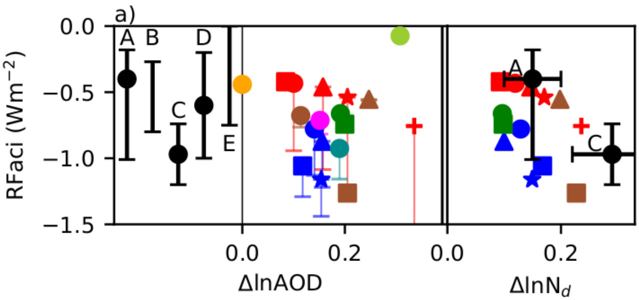

Obs.	●	
ECHAM6-HAM2.2	●	emiss.
CAM5.3	●	mphys.
SPRINTARS	●	mphys.
HadGEM/UKESM	■	ver.
CanESM2	●	
IPSL-CM5A-LR	●	
MIROC5	●	
MRI-CGCM3-p1	●	

- Observational uncertainty similar to model diversity.

Gryspeerdt et al., ACPD, 2019

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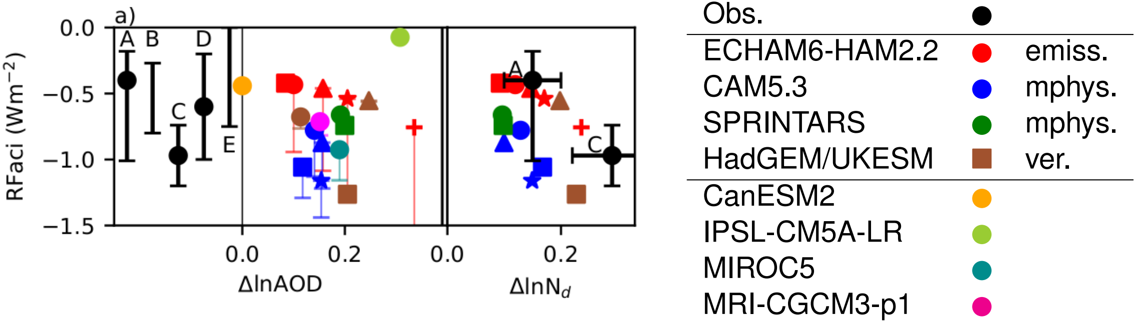

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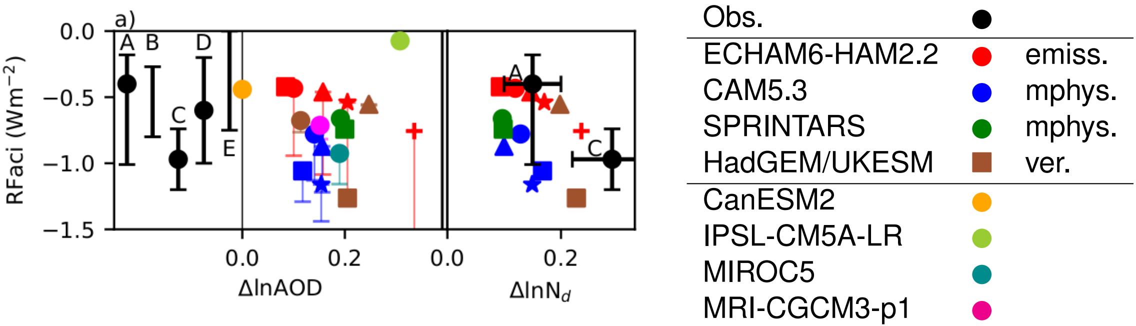
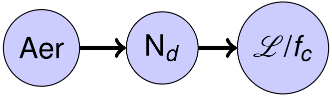


- Observational uncertainty similar to model diversity.
- Uncertainty in ΔN_d from uncertainty in anthropogenic aerosol fraction
- Variation in RFaci even if ΔN_d is known

Gryspeerdt et al., ACPD, 2019

Liquid cloud adjustments



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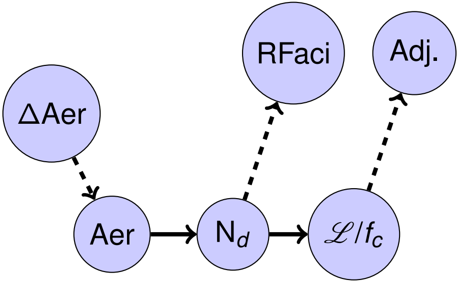

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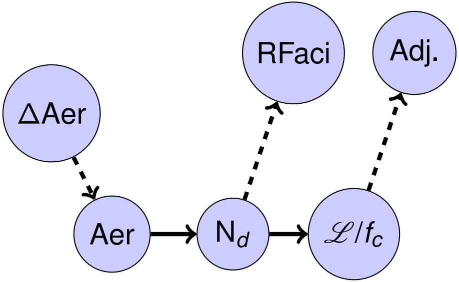

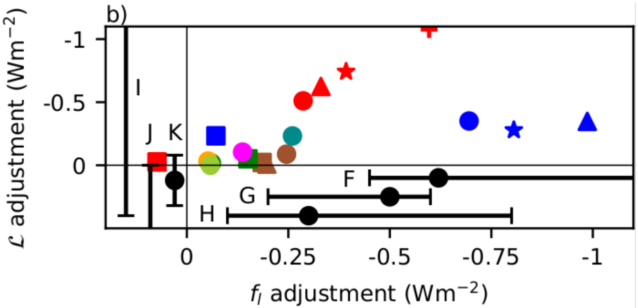

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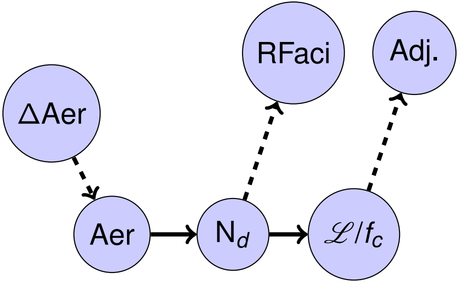

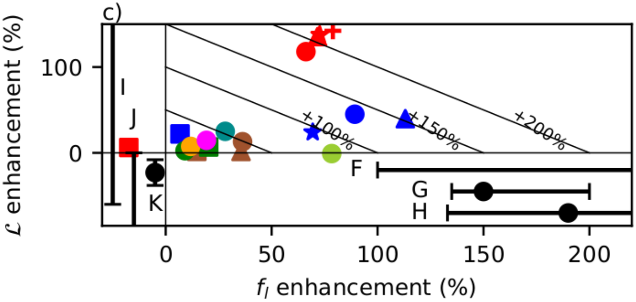

- Measuring adjustments as an enhancement of Twomey reduces impact of aerosol activation

Gryspeerdt et al., ACPD, 2019

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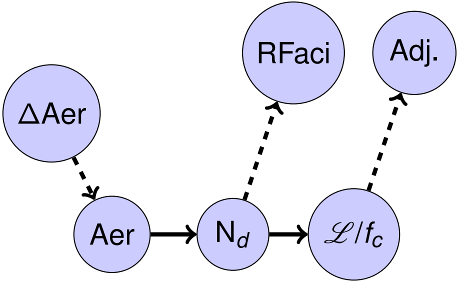

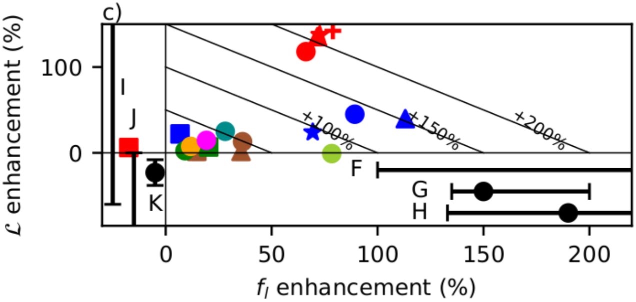

- Measuring adjustments as an enhancement of Twomey reduces impact of aerosol activation
- Observational estimates for CF adjustments are similar magnitudes

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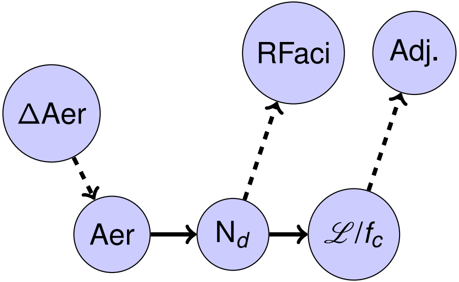
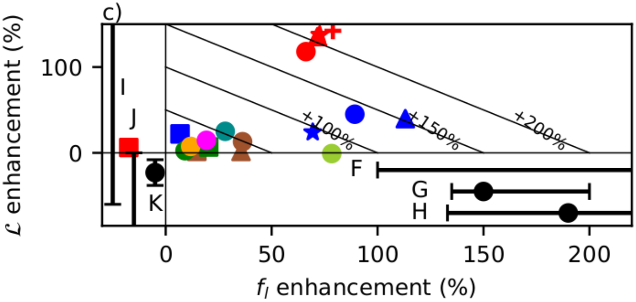
Liquid cloud adjustments





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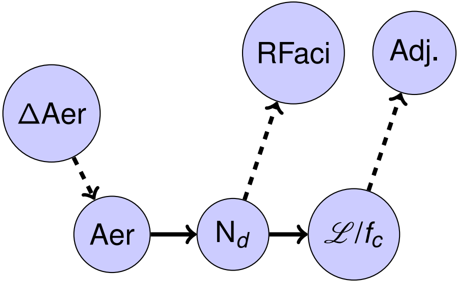
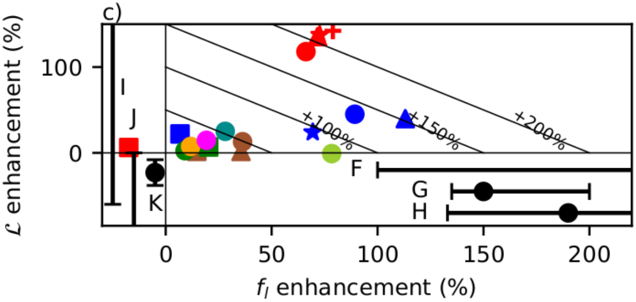


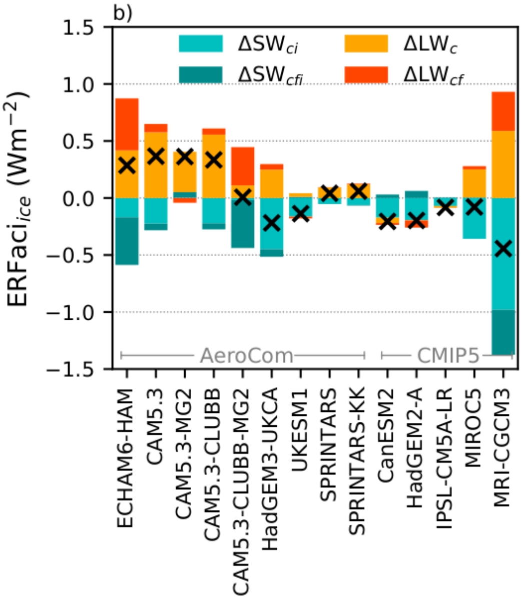


- Measuring adjustments as an enhancement of Twomey reduces impact of aerosol activation
- Observational estimates for CF adjustments are similar magnitudes
  - Are we getting really good at measuring the wrong thing?
- LWP adjustments are still poorly constrained

Gryspeerdt et al., ACPD, 2019

Forcing from ice clouds

- A large variation in ice cloud forcing
  - Range of -0.5 to +0.4 Wm^{-2}
  - Similar to Uncertainty in Twomey effect
- Potential difference between AeroCom and CMIP5 models
  - Not result of simulation protocol (see HadGEM2/UKESM)
  - Difference in satellite simulators?
- No strong observational constraints (yet)



What does my model look like?

Output	Notes
rsut	
rsutcs	
tcc	Or CALIPSO simulator
lcc, icc	Or CALIPSO simulator
lwp	
iwp	Avoid with satellite simulator
rlut	LW only
rlutcs	LW only
rsdt	*Can be calculated*
rsutnoa	*Approximate results without*
rsutcsnoa	*Approximate results without*
od550aer	*Optional*
cdnc	*Optional*

What do I need to do this?

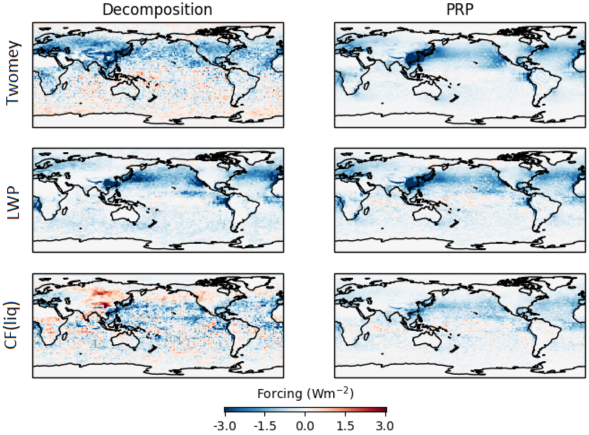
- PD and PI simulations
- Daily mean output (3 hourly is better)
- 5 years nudged is more than enough
  - ECHAM-HAM results indicate reasonable accuracy with one year of data
- AeroCom PII-IND3 setup is ideal

Method

- Described in Gryspeerdt et al, ACPD, 2019
- Python code available
- I can run analysis if you have the output

Summary

- Can decompose the aerosol forcing into components from a single pair of simulations



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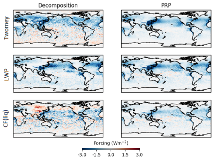

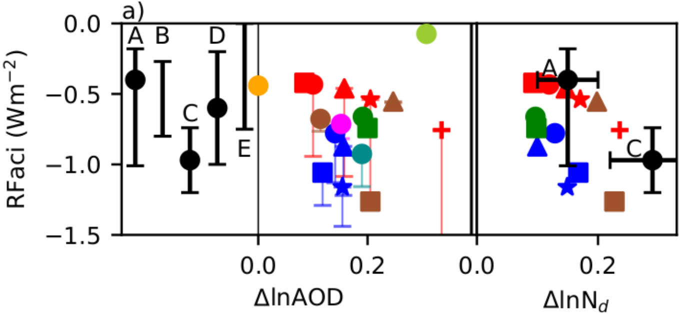

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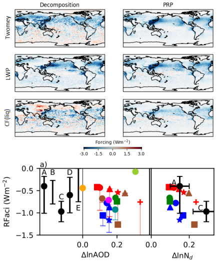

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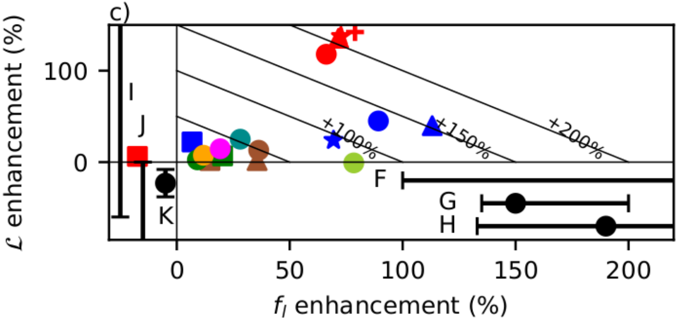

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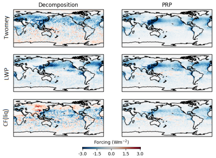

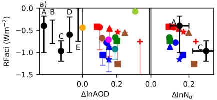

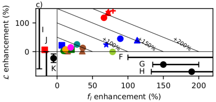

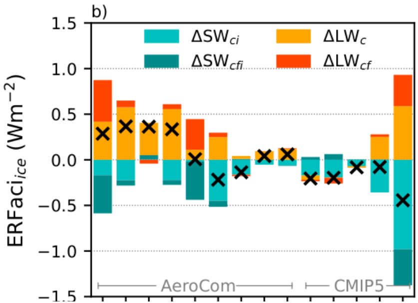

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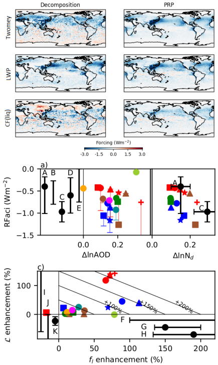
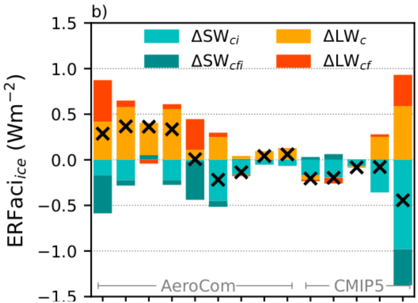
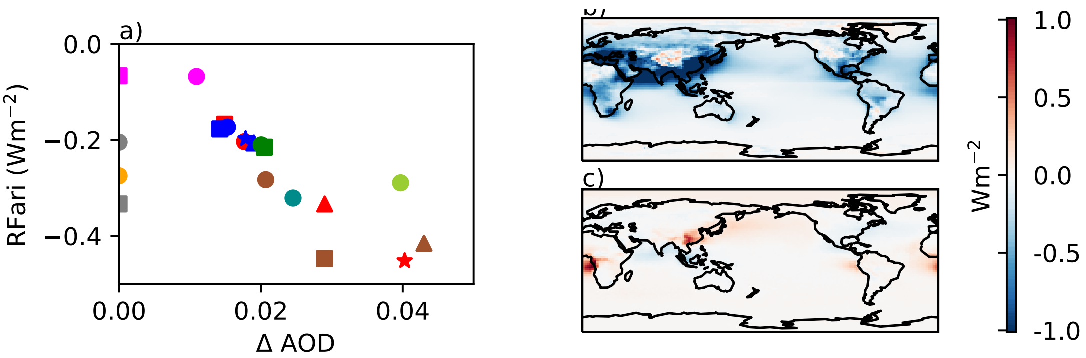


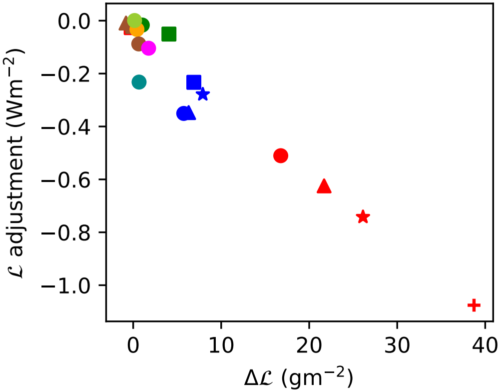


RFari



- RFari closely related to AOD change
- Above cloud RFari is a much smaller positive adjustment

LWP adjustment



To first order, LWP adjustment is a function of LWP change

Exact relationship appears to vary between models

Forcing spatial patterns