Retrieval of Cloud Condensation Nuclei to Quantify Radiative Forcing due to ACI

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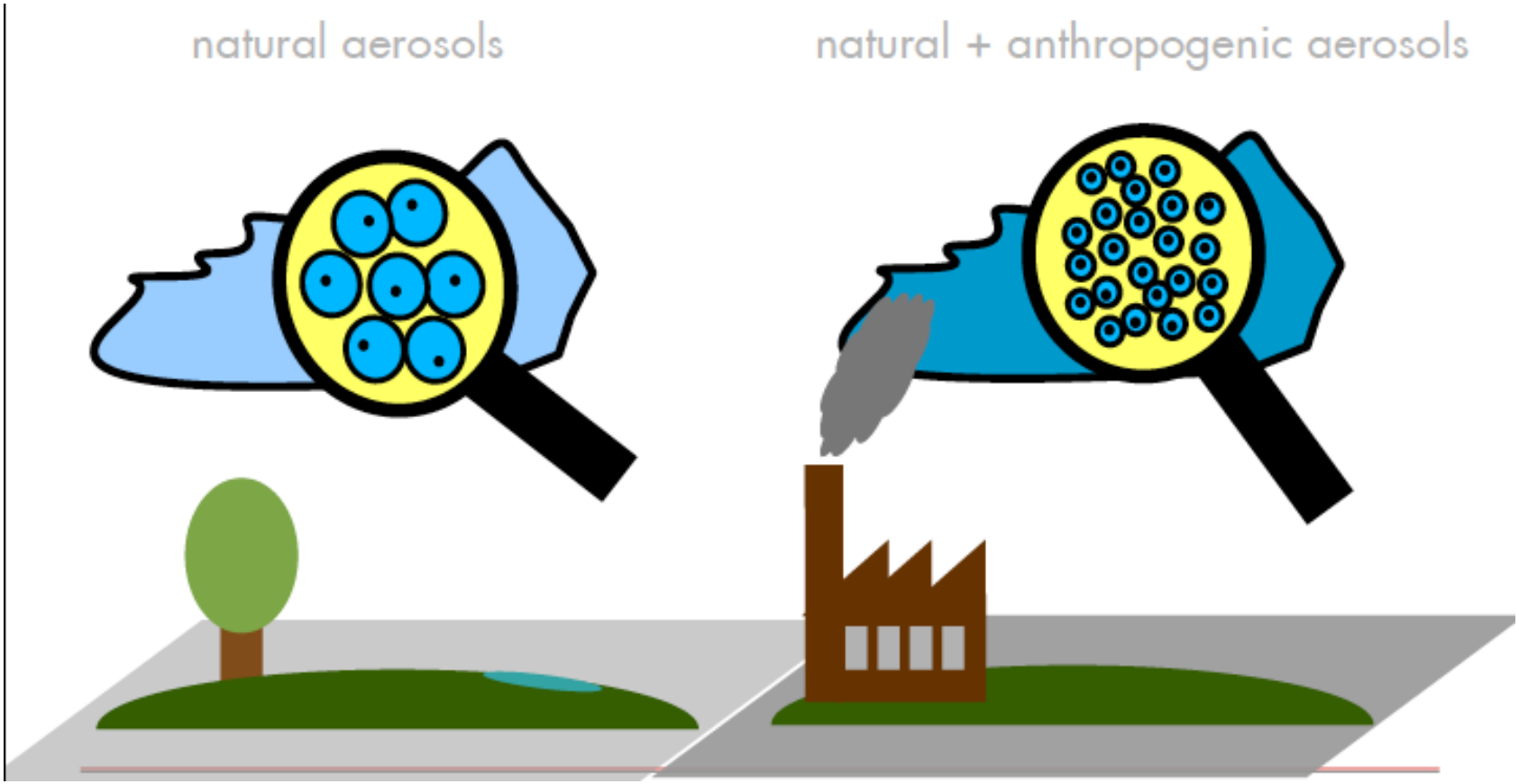
Radiative Forcing due to aerosol-cloud interactions (RFaci)

Instantaneous effect of aerosols on cloud droplet number concentration (N_d) and cloud albedo.



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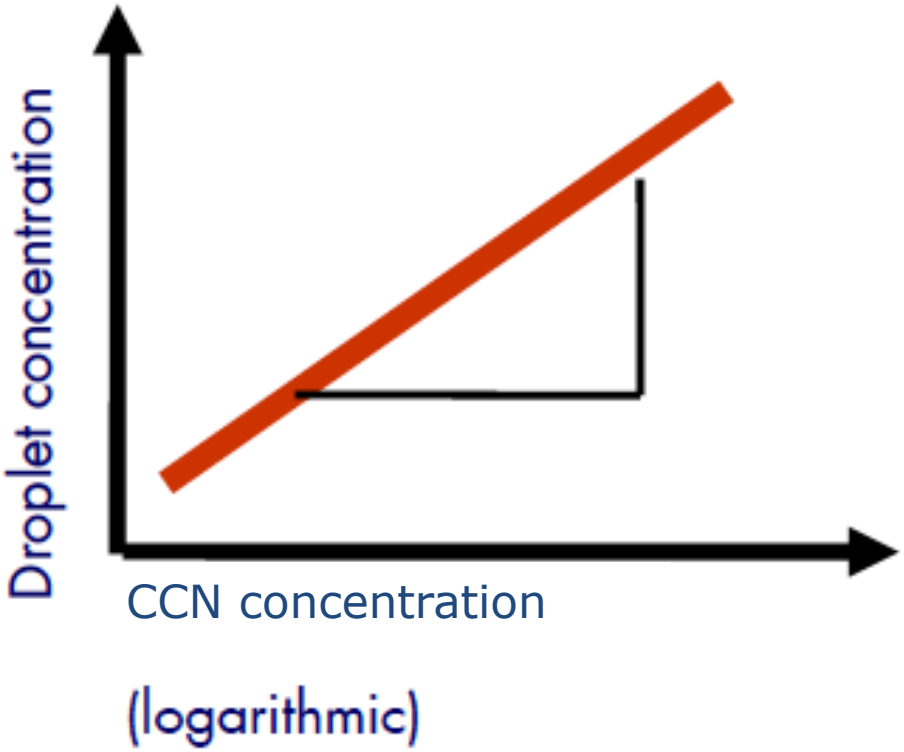
Susceptibility



$$S = \frac{d\log(Nd)}{d\log(n_{ccn})}$$

Satellite studies: 0.10-0.50
In situ / airborne: 0.25-0.90

Feingold et al, GRL, 2001
McComiskey and Feingold, GRL, 2008

Caveats of Satellite studies

- Variation in AOD is not only determined by particle concentration but also by variation in extinction cross section (AOD = N * σ).

- Use of Aerosol Index (AI) - the product of AOD with Angstrom Exponent - partly remedies this, but to what extend? Based mainly on qualitative arguments.

- Not all aerosols are suited as CCN (e.g. very small particles, hydrophobic mineral Dust)

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Size Matters More Than Chemistry for Cloud-Nucleating Ability of Aerosol Particles

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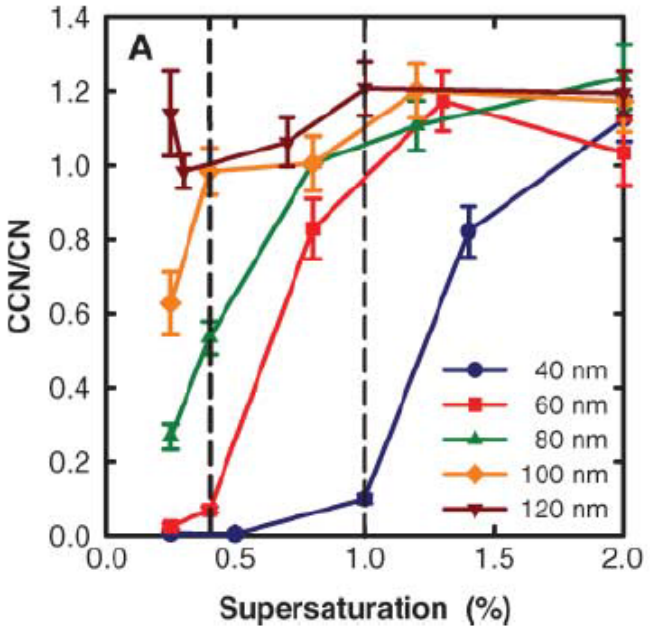

Only aerosols with $r > r_{lim}$ are suitable as CCN

Susceptibility from POLDER-3 and MODIS

- POLDER-3/PARASOL provides retrievals of particle column and size distribution.
- From this the column of particles with r > r_{lim} can be computed → proxy for CCN (N_{ccn})
- MODIS provides retrievals of cloud droplet number concentration (N_d).
- Aggregated to 1x1 degree. Use grid cells that contain both POLDER-3 aerosol retrievals and MODIS Nd retrievals.
- From binned Nccn - Nd relationship compute susceptibility $S = \frac{d\log(N\mathrm{d})}{d\log(N\mathrm{ccn})}$ using linear regression.

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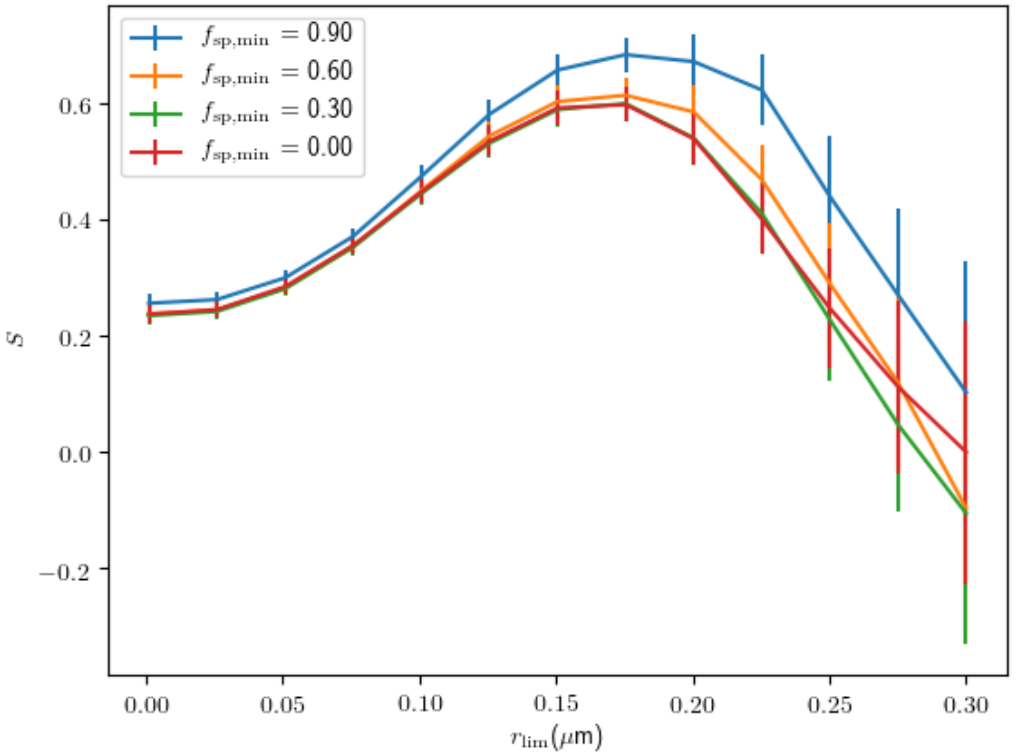
Dependence of Susceptibility on Size and Shape



- Inclusion of non-CCN yields too small susceptibility as they are not related to Nd.
- Best CCN proxy N_{ccn} for r>0.15 μm and f_sphere > 0.90.
- Taking a factor ~2 growth due to humidification into account, our r_{lim} corresponds to 0.075 μm dry radius (Dusek et al suggest ~0.06 μm).

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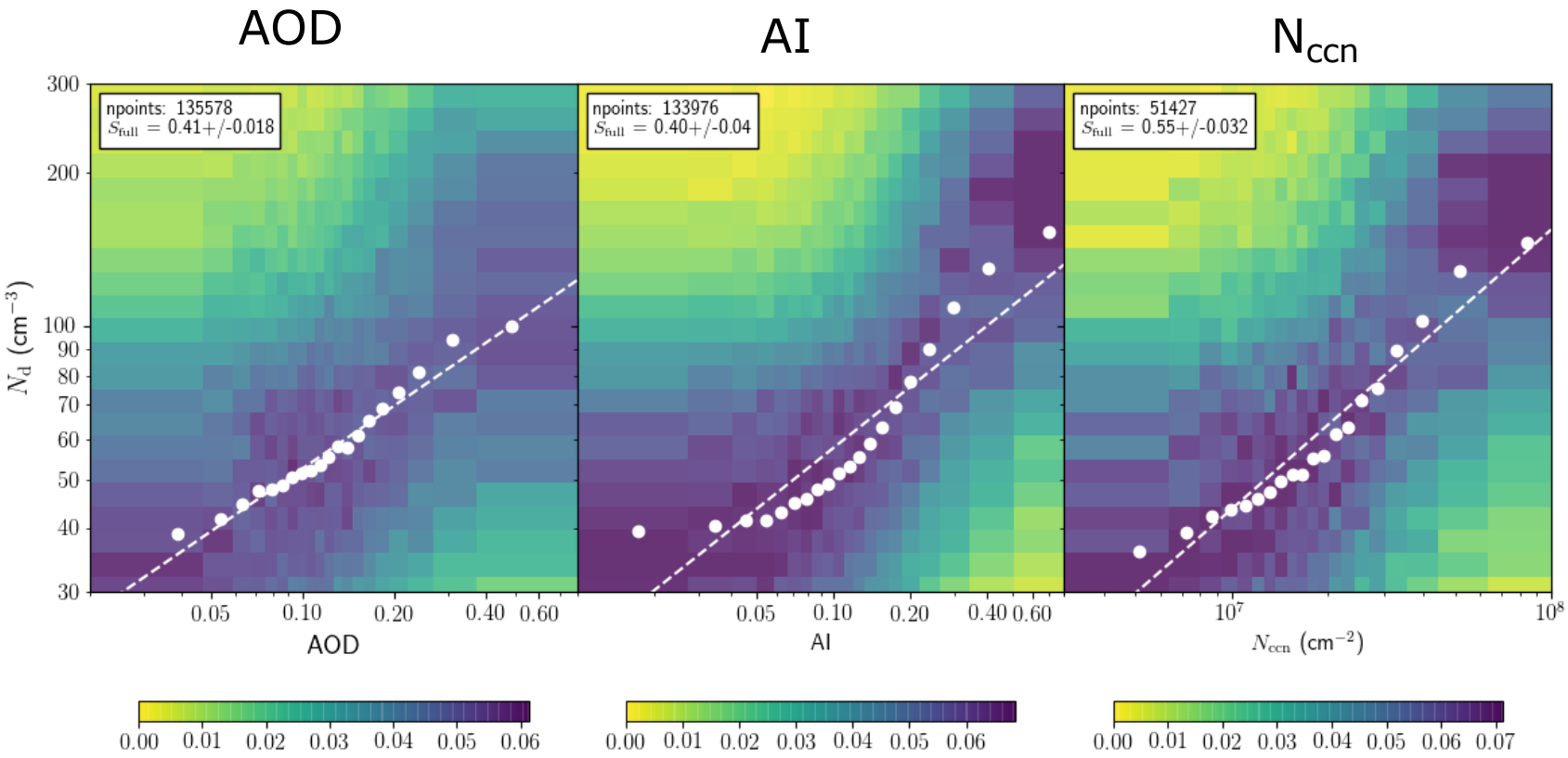
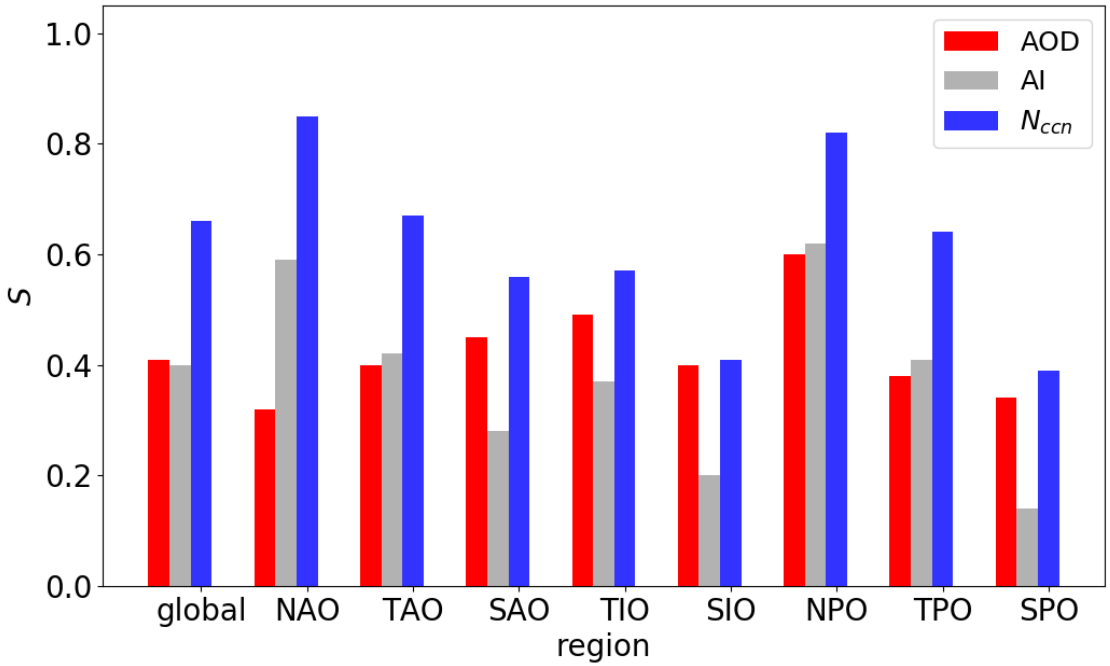
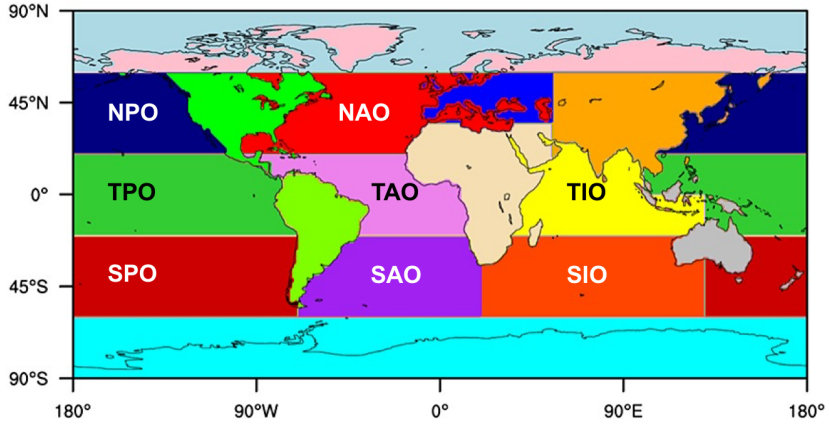
Aerosol - N_d relationships for AOD, AI and N_{ccn}



Susceptibilities for different regions

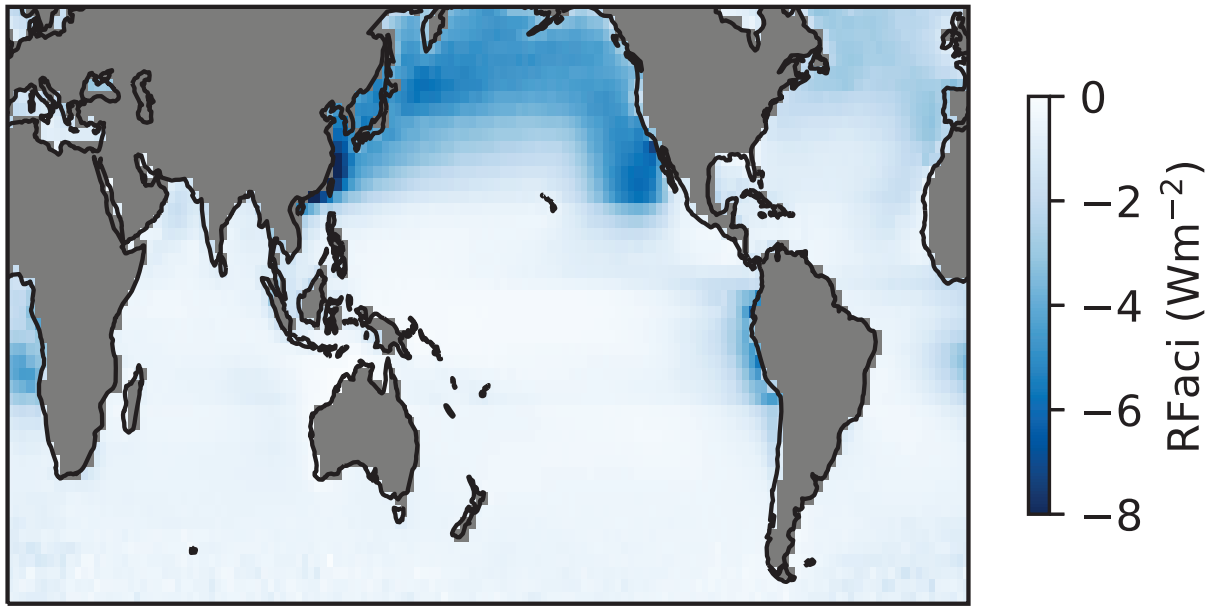
In the important regions, the new susceptibilities based on N_{ccn} are more than 50% higher than values based on AOD or AI ('old approach')





Radiative Forcing due to Aerosol Cloud Interactions (RFaci)

Use 5 different aerosol climate models to provide an estimate of the increase in N_{ccn} between Pre-Industrial (PI) and Present Day (PD).



Global ocean value: - 0.76 Wm^{-2}

Use ratio $RFaci_{global}$ / $RFaci_{ocean}$ from 13 different aerosol climate models to estimate contribution over land.

Global value: **-1.14 Wm^{-2}** (−0.84 to −1.72Wm^{-2})
AOD based: -0.33Wm^{-2} (−0.19 to −0.54Wm^{-2})
AI based: -0.80Wm^{-2} (−0.58 to −1.24Wm^{-2})

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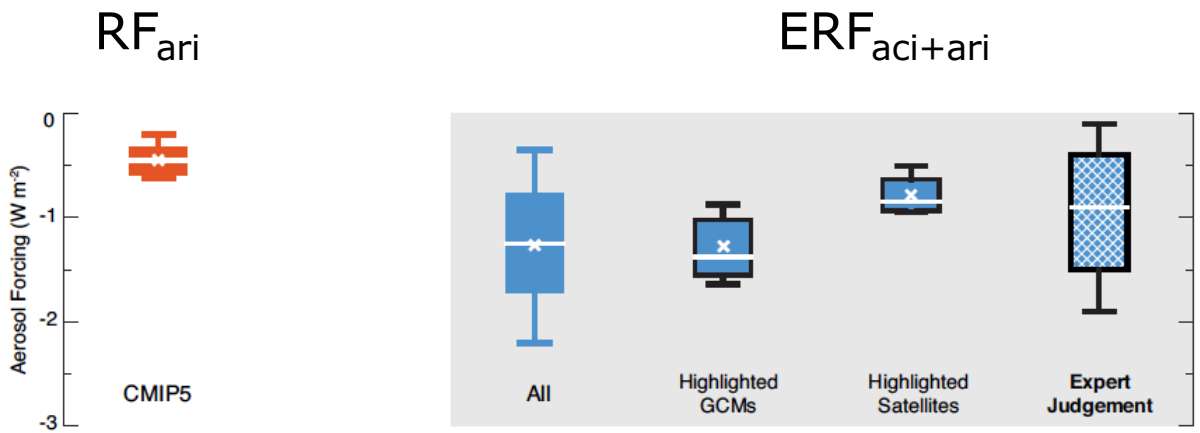
What does the IPCC 5th assessment say?

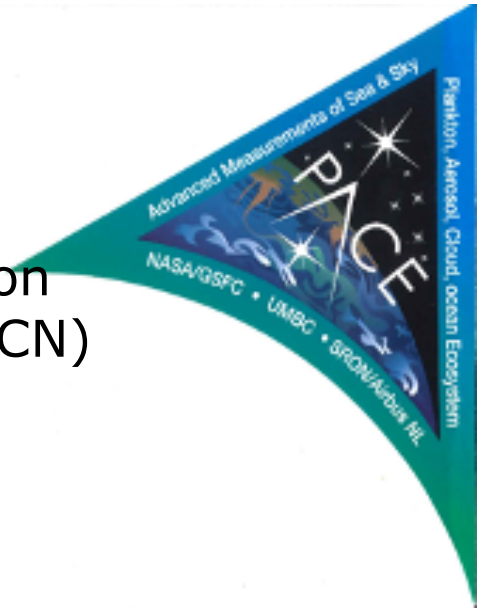


GCMs give ERF_{aci} ~= -0.90Wm^{-2}
Satellites give ERF_{aci} ~= -0.35Wm^{-2}

Expert judgement put more weight on satellite estimates:
ERF_{aci} = -0.45 Wm^{-2}, $ERF_{aci+ari}$ = -0.90Wm^{-2}

But most satellite studies in IPCC AR5 are based on AOD, some on AI .....
So, it seems that aerosol radiative forcing is underestimated.

What's next?



- Largest (known) uncertainty comes from the contribution over land to RFaci. Strong need for accurate aerosol (CCN) retrievals over land.

- SPEXone on PACE (launch 2023) will provide these accurate retrievals over land.

- HARP-2 on PACE will provide accurate retrievals of CDNC.

- To go from RFaci to ERFaci, the effect of aerosol on cloud fraction is the big unknown → difficult to estimate because of aerosol swelling.

- SPEXone on PACE will provide accurate retrievals of the aerosol refractive index → amount of aerosol water. This makes it possible to define CCN based on dry aerosol size → removes swelling effect.

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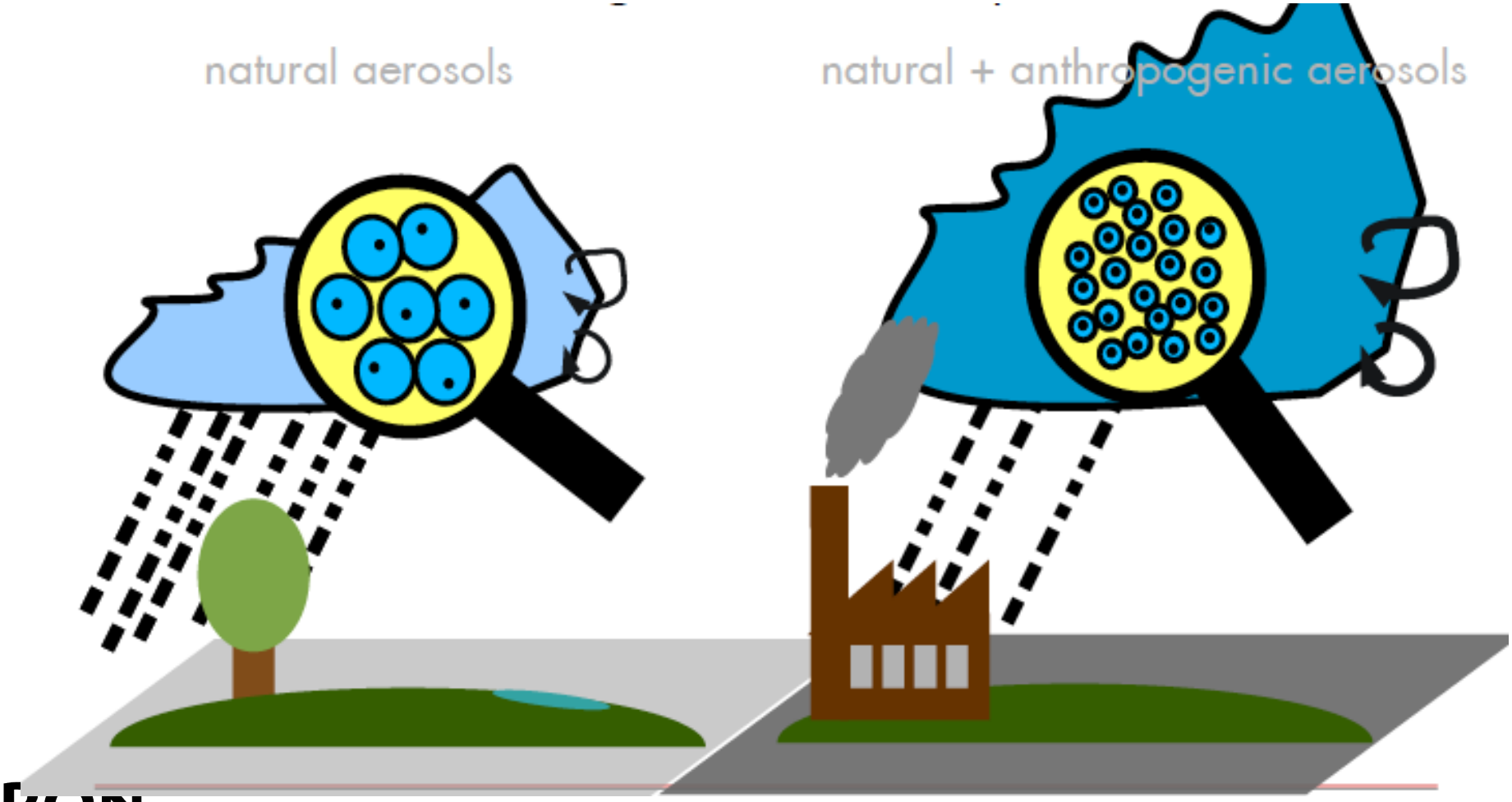
BACKUP SLIDES

Effective Radiative Forcing due to aerosol-cloud interactions (ERFaci)

Includes also cloud adjustments (Liquid Water Path, Cloud Fraction, etc.)



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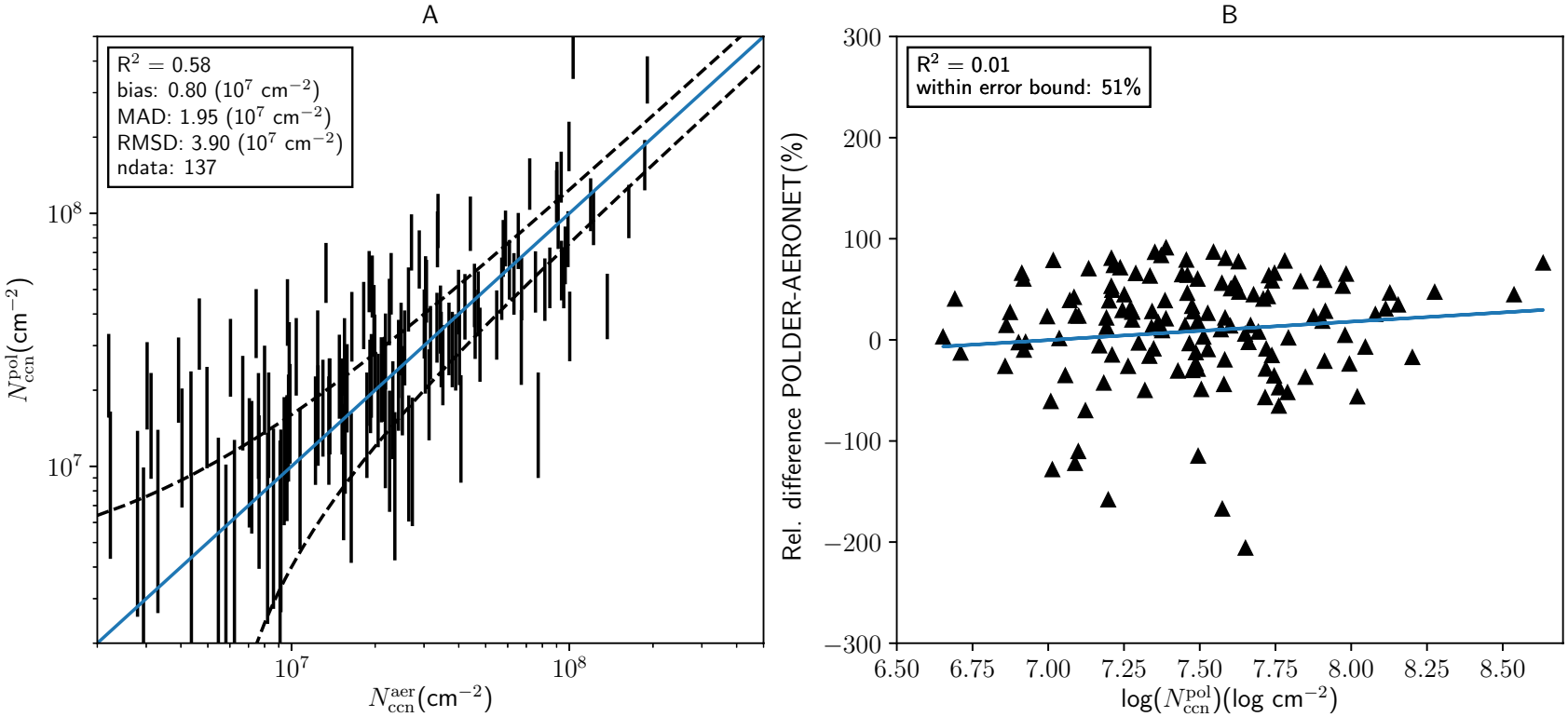
How well can we retrieve Nccn?



- Synthetic retrievals suggest an accuracy of 0.20 Nccn + 4 10^6 cm^{-2}.
- 51% of the data have a difference with AERONET smaller than this value.
- This confirms that it is a reasonable error estimate, as errors in the AERONET retrievals also contribute to the differences.

How do retrieval errors affect susceptibility?

ARTICLE

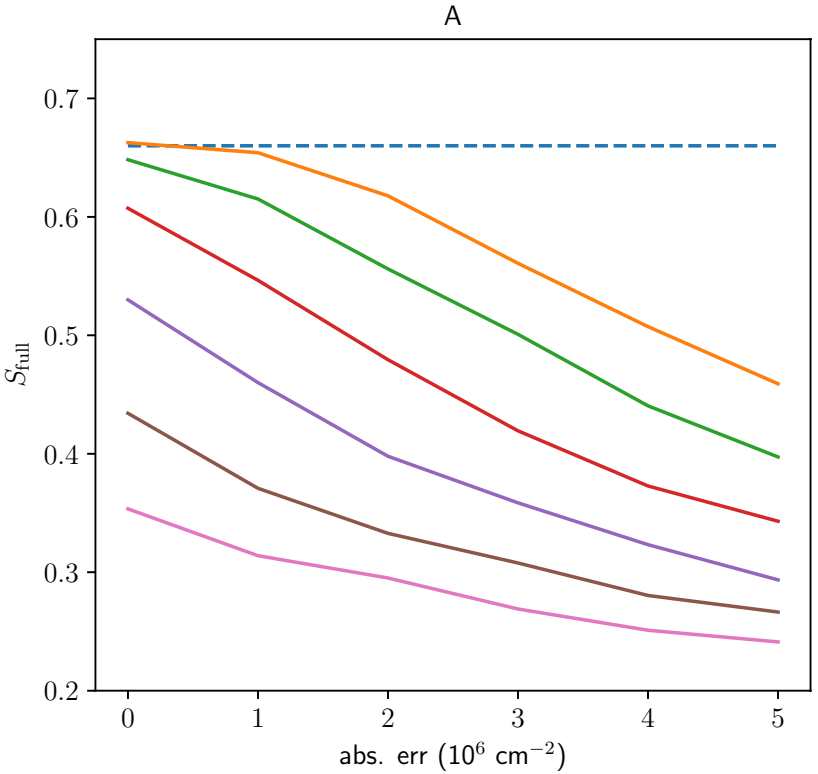
DOI: 10.1038/s41467-018-05028-4 OPEN

Observational constraint on cloud susceptibility weakened by aerosol retrieval limitations

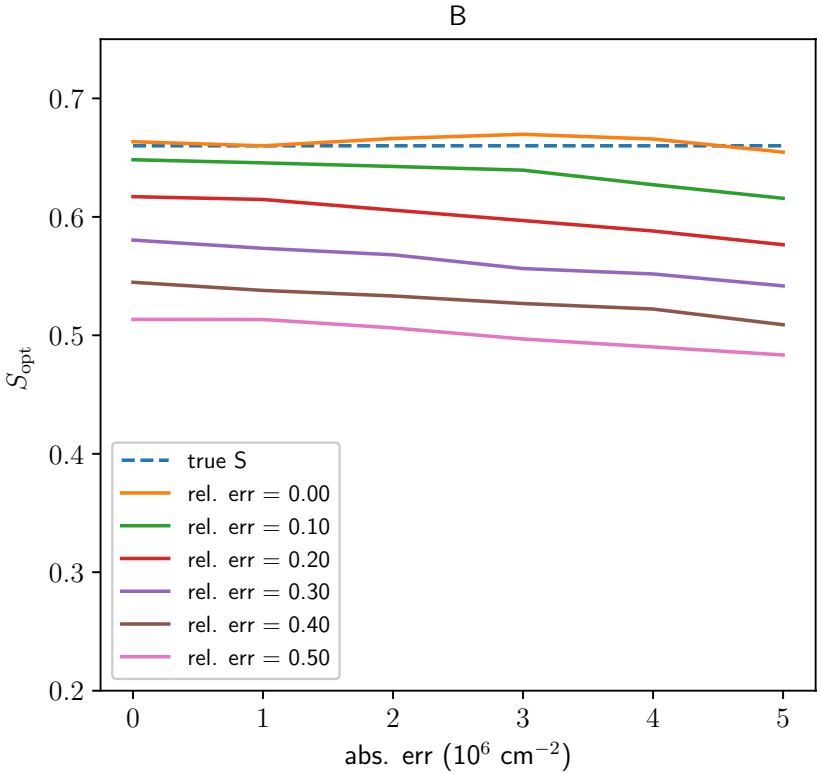
Po-Lun Ma[1], Philip J. Rasch[1], Hélène Chepfer[2,3], David M. Winker[4] & Steven J. Ghan[1]

How do retrieval errors affect susceptibility?

Using all retrievals



Using only Nccn > 10^7 cm^{-2}



- Measurement errors at low Nccn values lead to strong underestimation of S.
- Leaving out small values largely remedies this effect → closer to true S.

- Same reasoning holds for AOD and AI, but previous RFaci estimates did not exclude small values.

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From Susceptibility to Forcing

- Use 5 different aerosol climate models to provide an estimate of the increase in N_{ccn} between Pre-Industrial (PI) and Present Day (PD).

- Compute the increase in N_d: $\Delta\log(N_d) = S * \Delta\log(N_{ccn})$.

- From ΔN_d compute the change in cloud albedo (Twomey) and the corresponding Radiative Forcing (RFaci).

- This gives 5 estimates of RFaci over the ocean (as POLDER only provides sufficiently accurate information over ocean).

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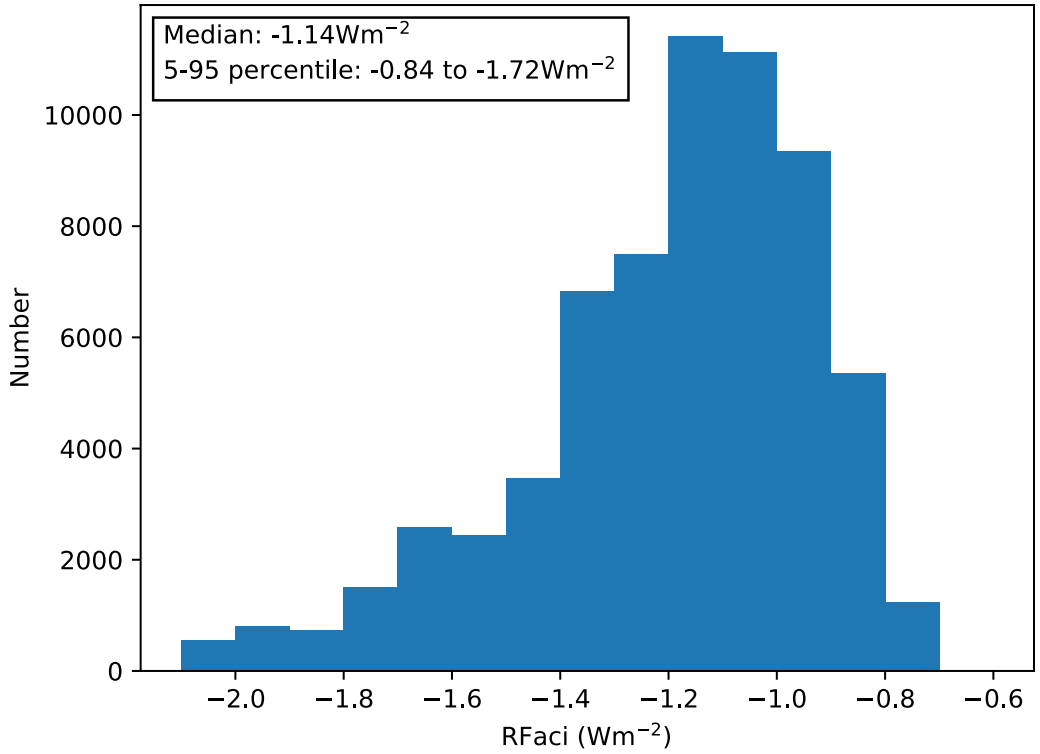
Global RFaci estimate

- Use ratio $RFaci_{global}$ / $RFaci_{ocean}$ from 13 different aerosol climate models.
- Combine with 5 estimates of $RFaci_{ocean}$ and the uncertainty estimate on S.



The uncertainty range is dominated by uncertainty in $RFaci_{global}$ / $RFaci_{ocean}$. This uncertainty term alone results in a range -0.85 to -1.70 Wm^{-2}.