



A synthesis of observations of aerosol-cloud interactions over the pristine, biologically active Southern Ocean and their implications for global climate model predictions

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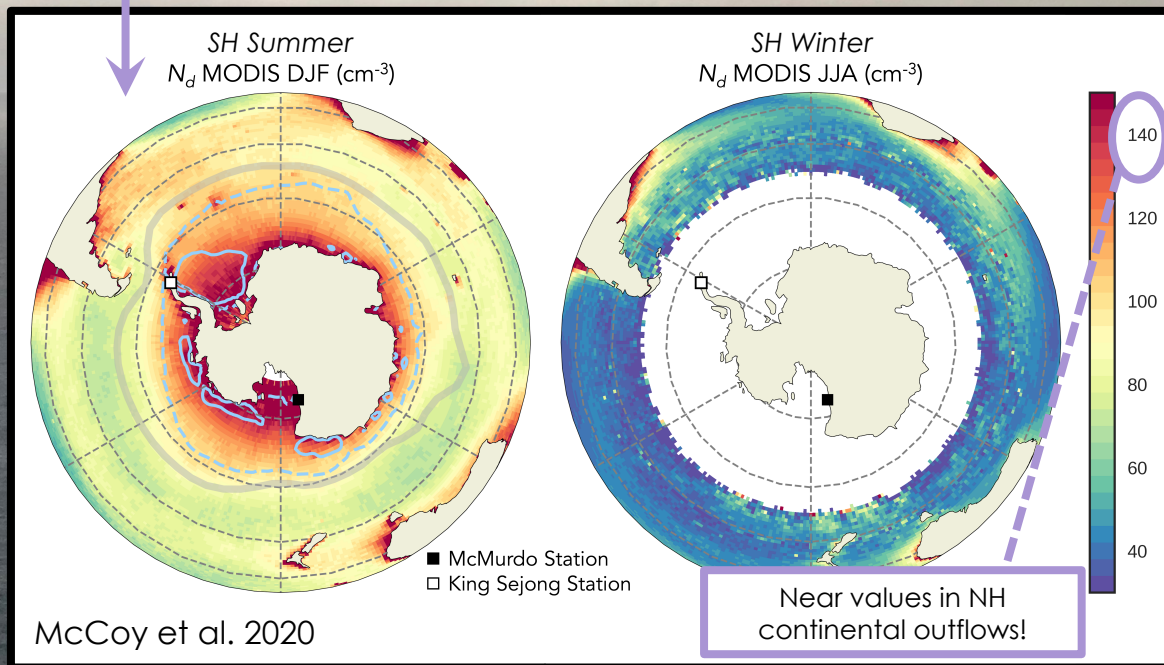
McCoy, I. L., McCoy, D. T., Wood, R., Regayre, L., Watson-Parris, D., Grosvenor, D. P., Mulcahy, J. P., Hu, Y., Bender, F. A., Field, P. R., Carslaw, K. S., Gordon, H. (2020). The hemispheric contrast in cloud microphysical properties constrains aerosol forcing. *Proc Natl Acad Sci U S A*, 117(32), 18998-19006. doi:10.1073/pnas.1922502117

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Where our story begins...



N_d , Droplet Number Concentration (cm^{-3})



Painemal & Zuidema, 2011; Painemal et al. 2012a; D. T. McCoy et al. 2017; Bennartz & Rausch, 2017a;

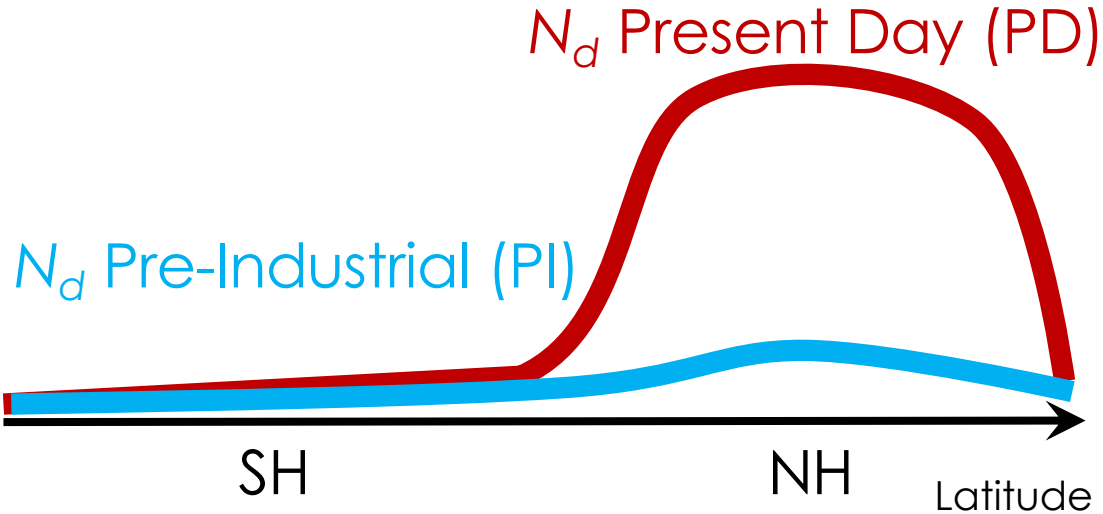
Grosvenor et al. 2018; Witte et al. 2018; Ahn et al. 2018; D. T. McCoy et al. 2018; Kang et al. 2021

How can we use present day N_d to constrain RF_{aci} ?



Hamilton et al. 2014
SH Oceans
 \cong

Pre-Industrial Environment



$$NH_{PD} - SH_{PD} \cong PD - PI$$

McCoy et al. 2020

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N_d Datasets for Observational Constraint

Satellite Observations:

- **MODIS** Aqua 2003-2015 (Grosvenor and Wood 2014)

Models:

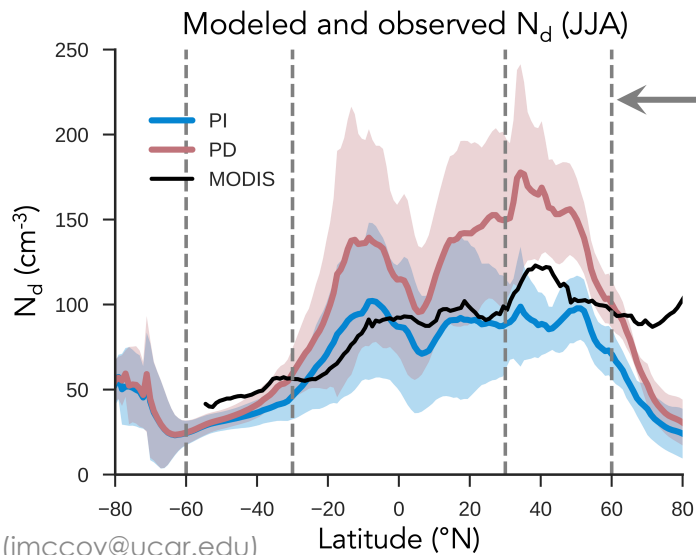
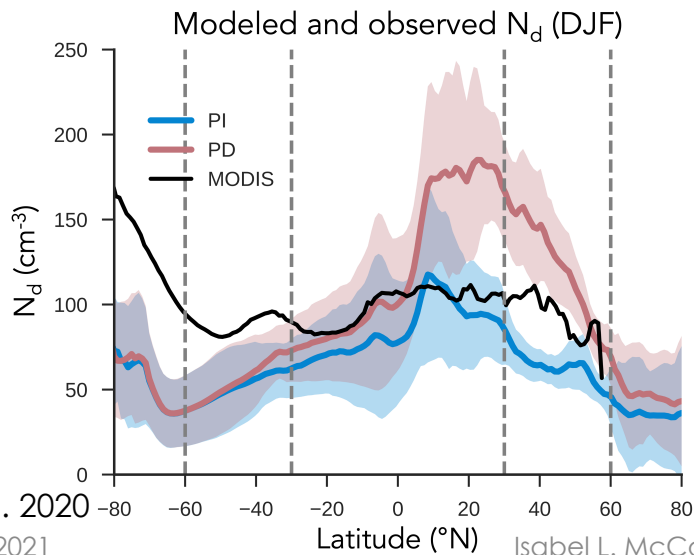
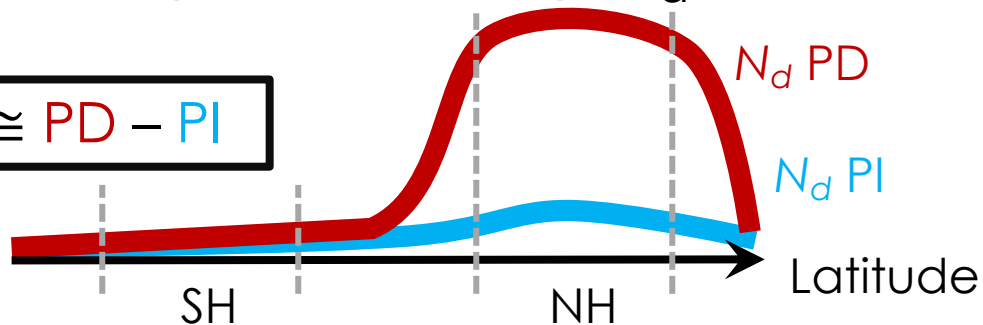
- **Aerocom phase II indirect 3:** CAM5, CAM5-CLUBB, CAM5-MG2, CAM5-CLUBB-MG2, ECHAM6.1.0-HAM2.2, SPRINTARS, and SPRINTARSKK
- Sensitivity studies in **HadGEM3-GA6 to 7.1** (Mulcahy et al. 2018)
- **Perturbed Parameter Ensemble (PPE) from HadGEM-GA4-UKCA** with 26 aerosol process, emission and deposition parameters simultaneously perturbed (Collins et al., 2010, Yoshioka et al., 2019). Emulation of PPE members as in Watson-Parris et al. 2019.

Exploring
uncertainty
between GCMs

Exploring
uncertainty *within* a
single GCM

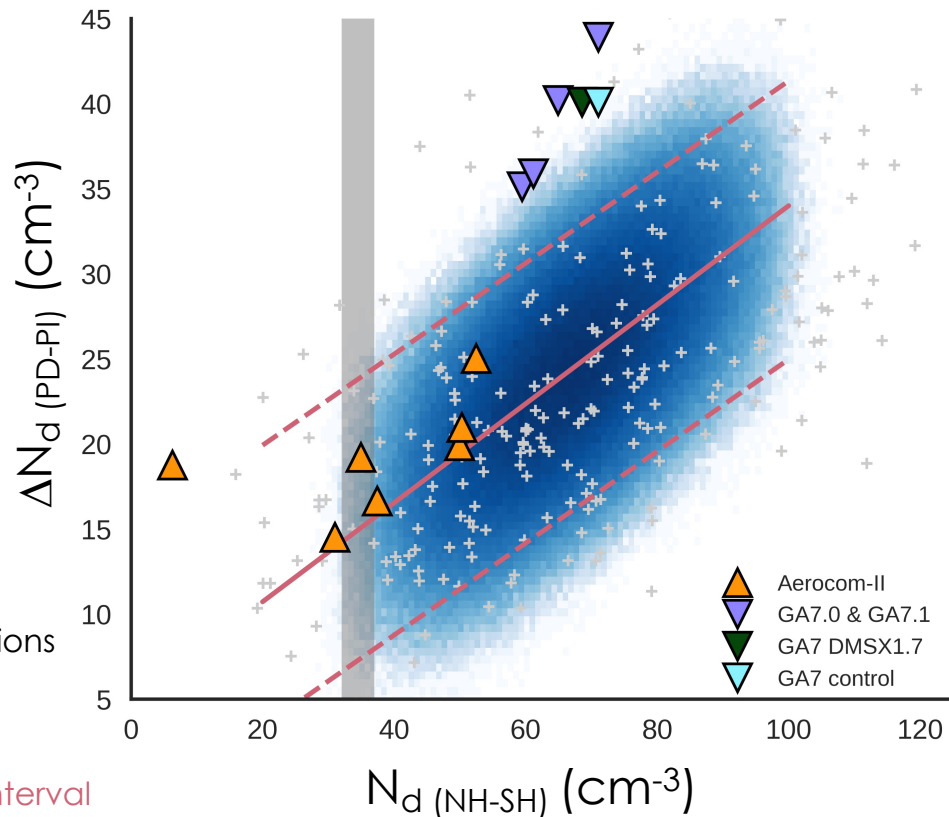
How can we use present day N_d to constrain RF_{aci} ?

$$NH_{PD} - SH_{PD} \cong PD - PI$$



Does $NH_{PD} - SH_{PD} \cong PD - PI$?

Yes, the hemispheric contrast contains information about the change in N_d from the pre-industrial.



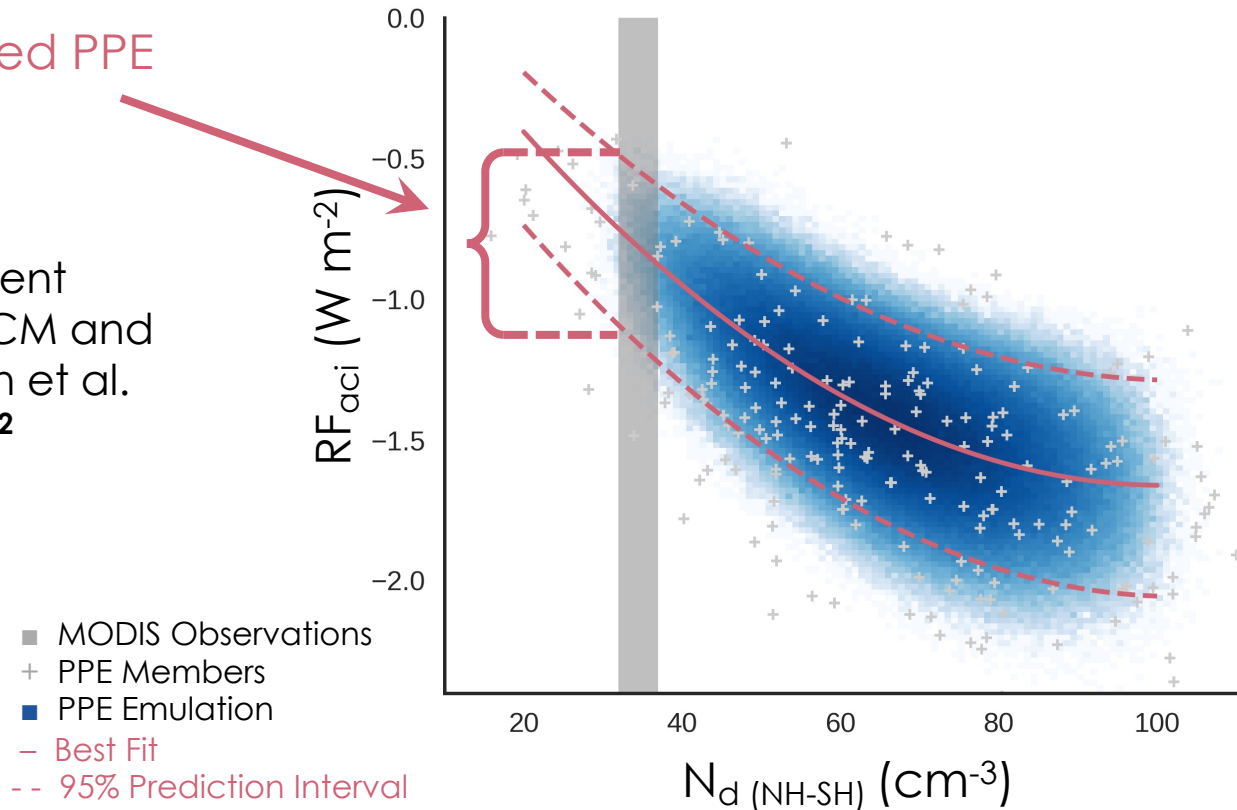
- MODIS Observations
- + PPE Members
- PPE Emulation
- Best Fit
- 95% Prediction Interval

- ▲ Aerocom-II
- ▼ GA7.0 & GA7.1
- ▼ GA7 DMSX1.7
- ▼ GA7 control

Can we constrain RF_{aci} with $N_d(NH-SH)$?

The MODIS constrained PPE
 RF_{aci} range is:
-1.20 to -0.60 Wm^{-2}

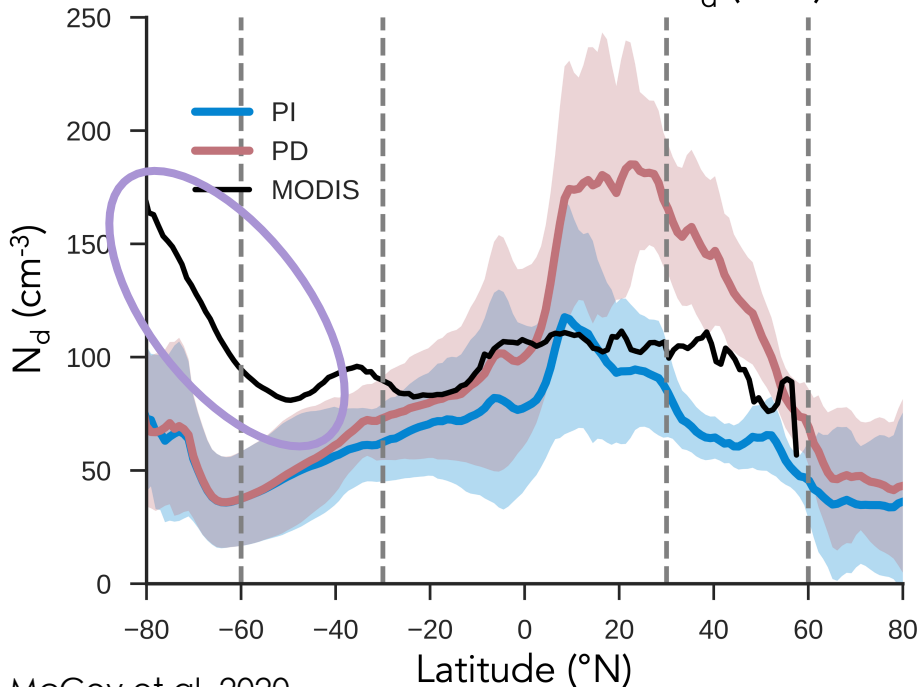
Comparable to the recent
synthesis range from GCM and
remote sensing (Bellouin et al.
2019): **-1.2 to -0.35 Wm^{-2}**



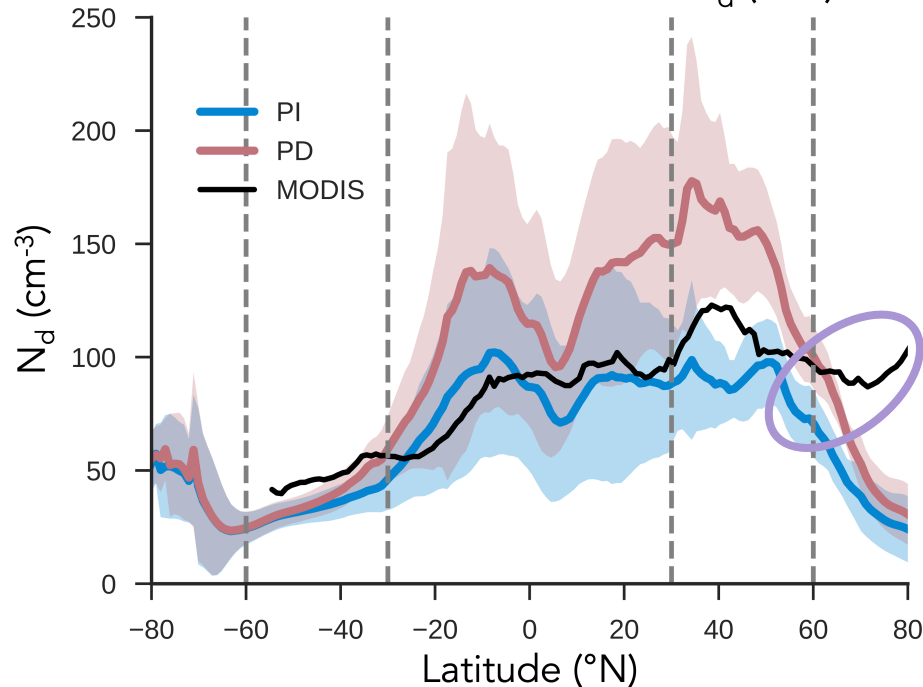
Why are so many models and PPE members outside of the observed range of N_d (NH-SH)?

Summertime mid-latitude N_d is too low in models.

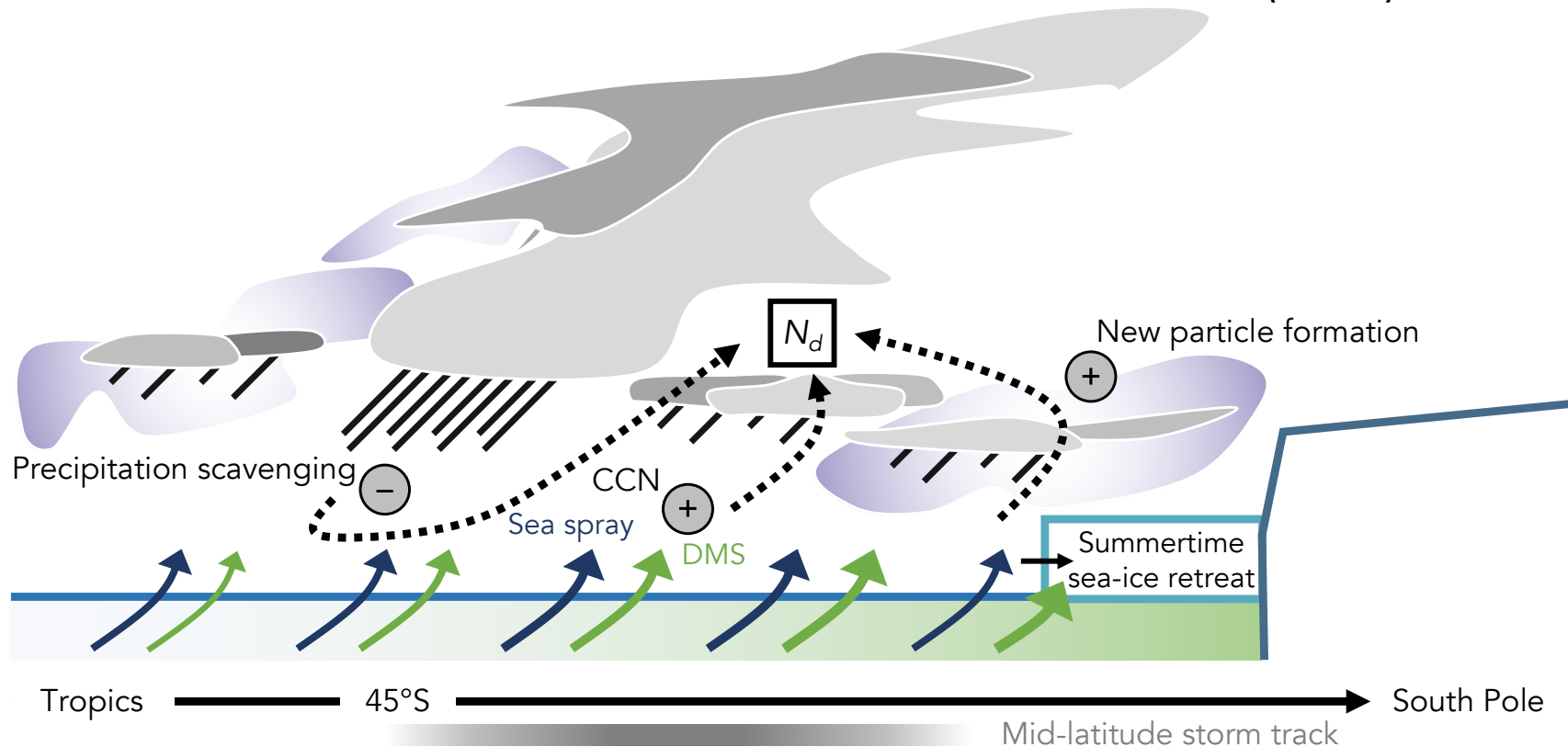
Modeled and observed N_d (DJF)



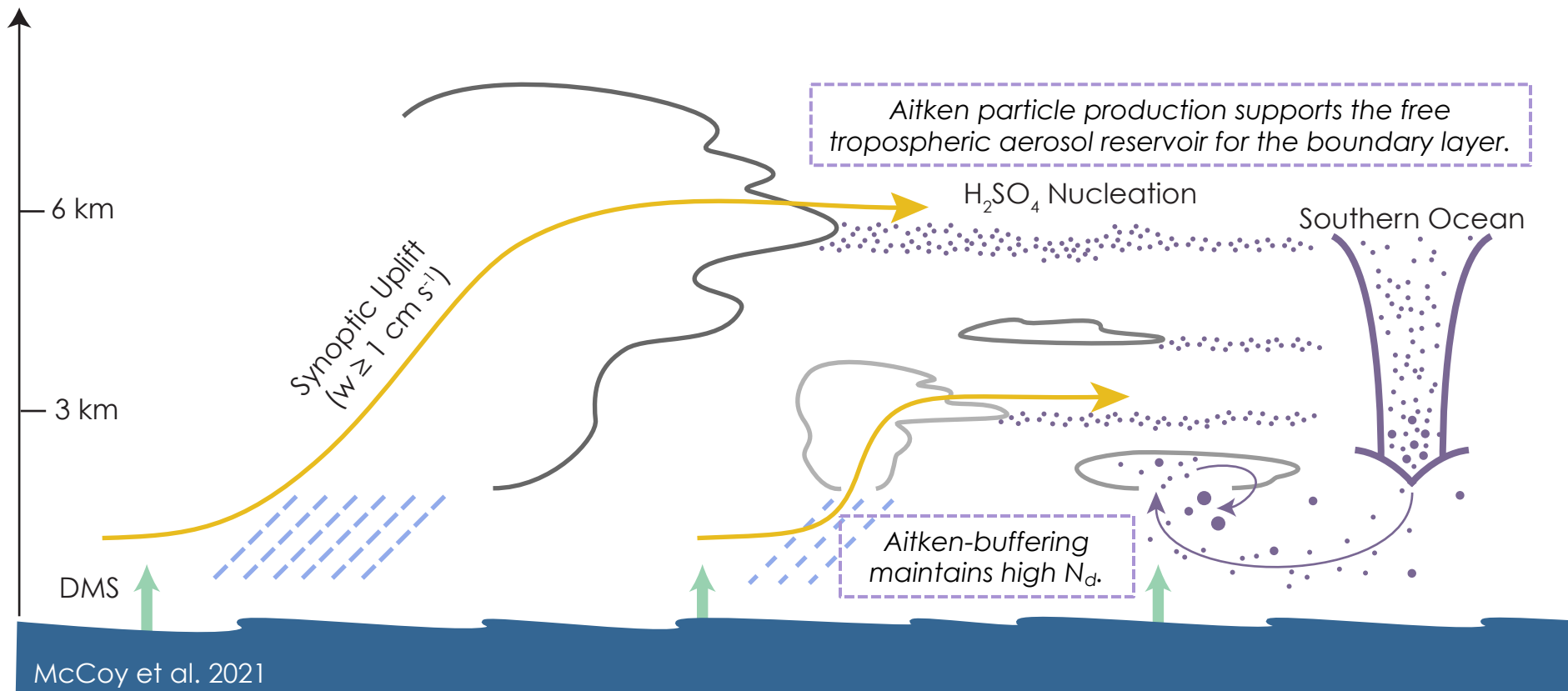
Modeled and observed N_d (JJA)



Uncertainty in aerosol indirect forcing is dominated by uncertainty in the pre-industrial aerosol state (i.e. natural emissions) (Carslaw et al. 2013). Natural emissions control Southern Ocean cloud condensation nuclei (CCN).



In-situ sampling of SO aerosol-cloud interactions reveals underprediction of small particles critical for N_d



Summary

- The hemispheric contrast in cloud droplet number concentration (N_d) can be used to constrain ΔN_d (PD-PI), RF_{aci} .
- N_d in pristine, biologically active environments is underpredicted in GCMs.
- *In situ* sampling of aerosol-cloud interactions in these environments reveal critical mechanisms for N_d .

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