

A new approach to quantifying aerosol-cloud radiative effect through process-based constraints on climate model parameters

Kunal Ghosh

Lea Provost, Leighton Regayre and Ken Carslaw (ICAS, University of Leeds),

Jill S Johnson, Iain Webb, Emmanouil Kalligeris, and Jeremy Oakley (MPS, University of Sheffield)

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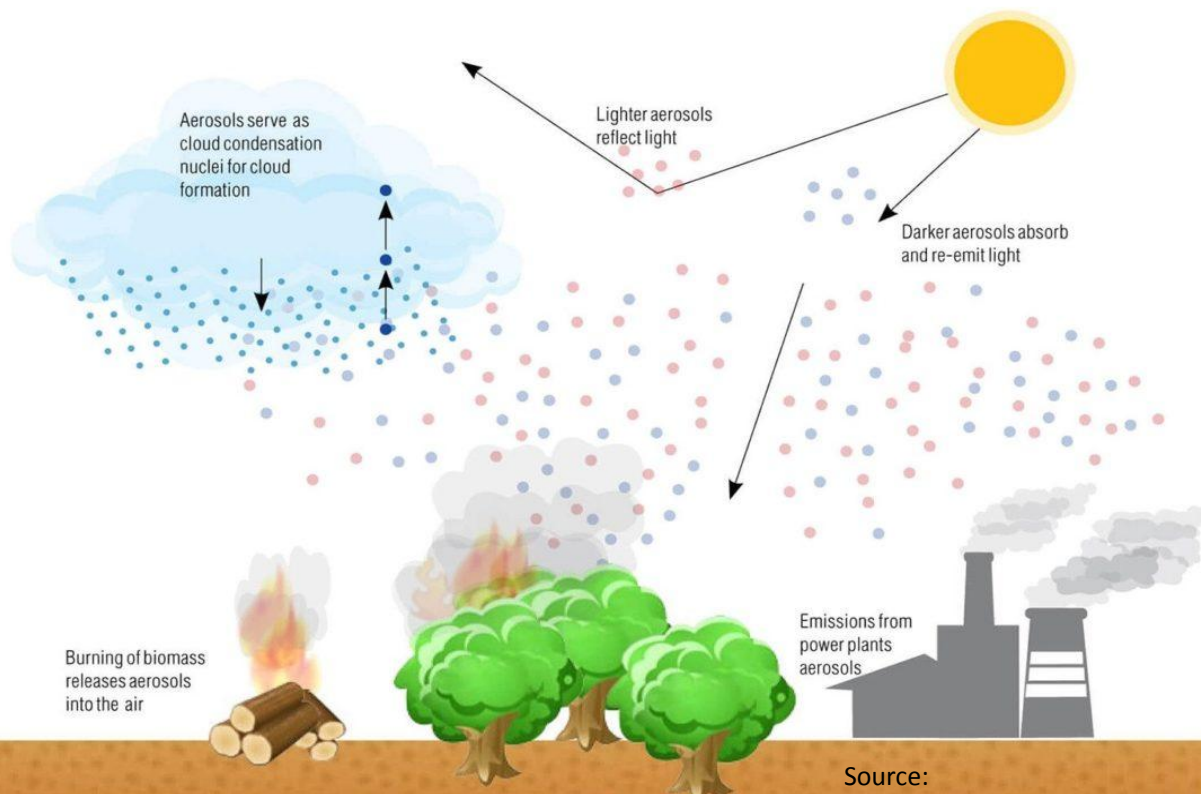
Aerosols (particles suspended in the air) affect **Earth's radiative balance** in two ways:

Indirectly

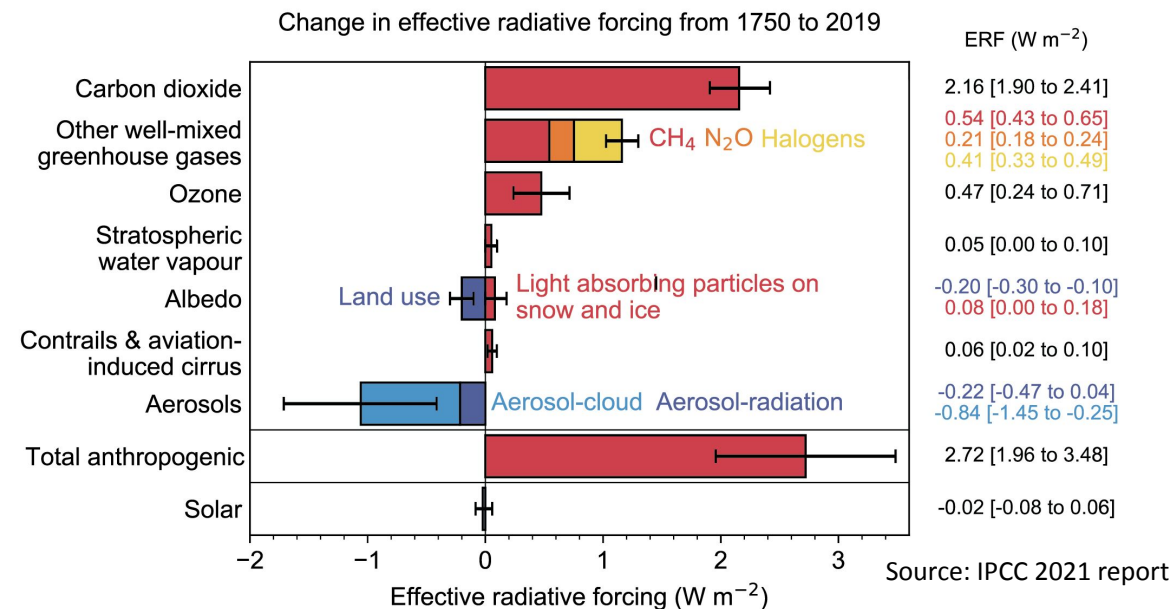
Seeds for cloud formation. Affect cloud properties and lifetime.

Directly

Aerosols **absorb or reflect** sunlight. Influence Earth's energy budget.

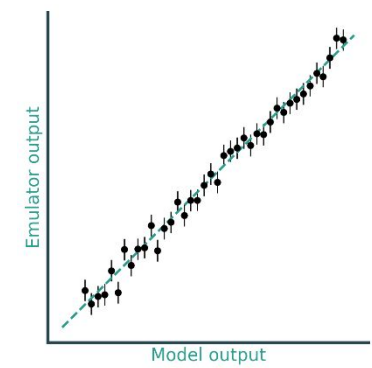
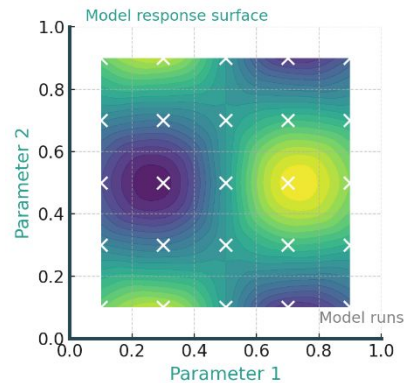
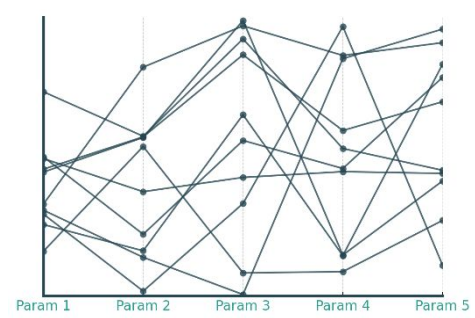
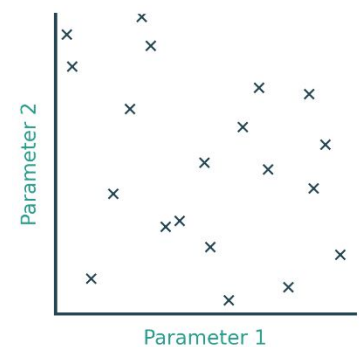
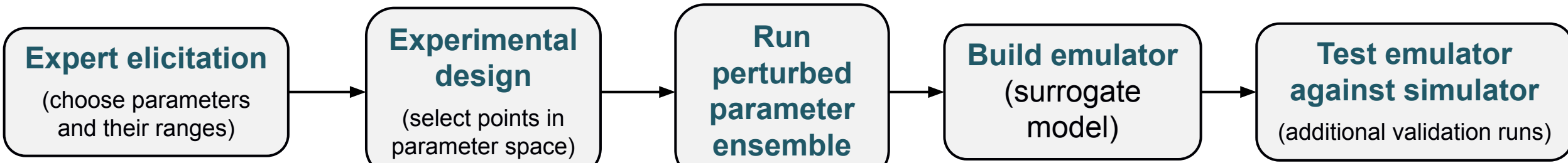


Aerosol–cloud interactions dominate the uncertainty in climate forcing estimates.



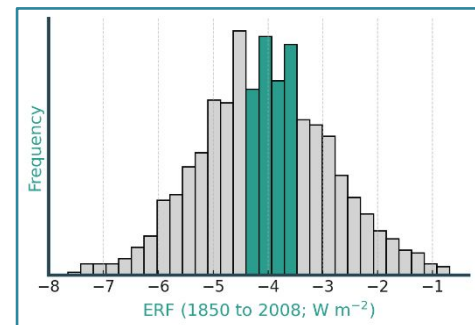
We need to constrain aerosol-cloud interactions to improve predictions

A set of model simulations where **key parameters** are systematically varied within plausible ranges to **explore uncertainty**



Uncertainty Analysis and Model Evaluation

- **Explore** model outputs and their responses
- **Identify key sources** of uncertainty (variance-based sensitivity analysis)
- **Constrain** the model output (history matching)



State variables

1. Cloud droplet number concentration (N_d)
2. Cloud liquid water path (LWP)
3. Specific humidity (q)
4. Others (cloud fraction, critical size, etc.)

Process based relationship

N_d -LWP relationship

Has been used previously in:




- Satellite related studies
- Default global climate models (GCM) cases.

Not studied in relation to PPE

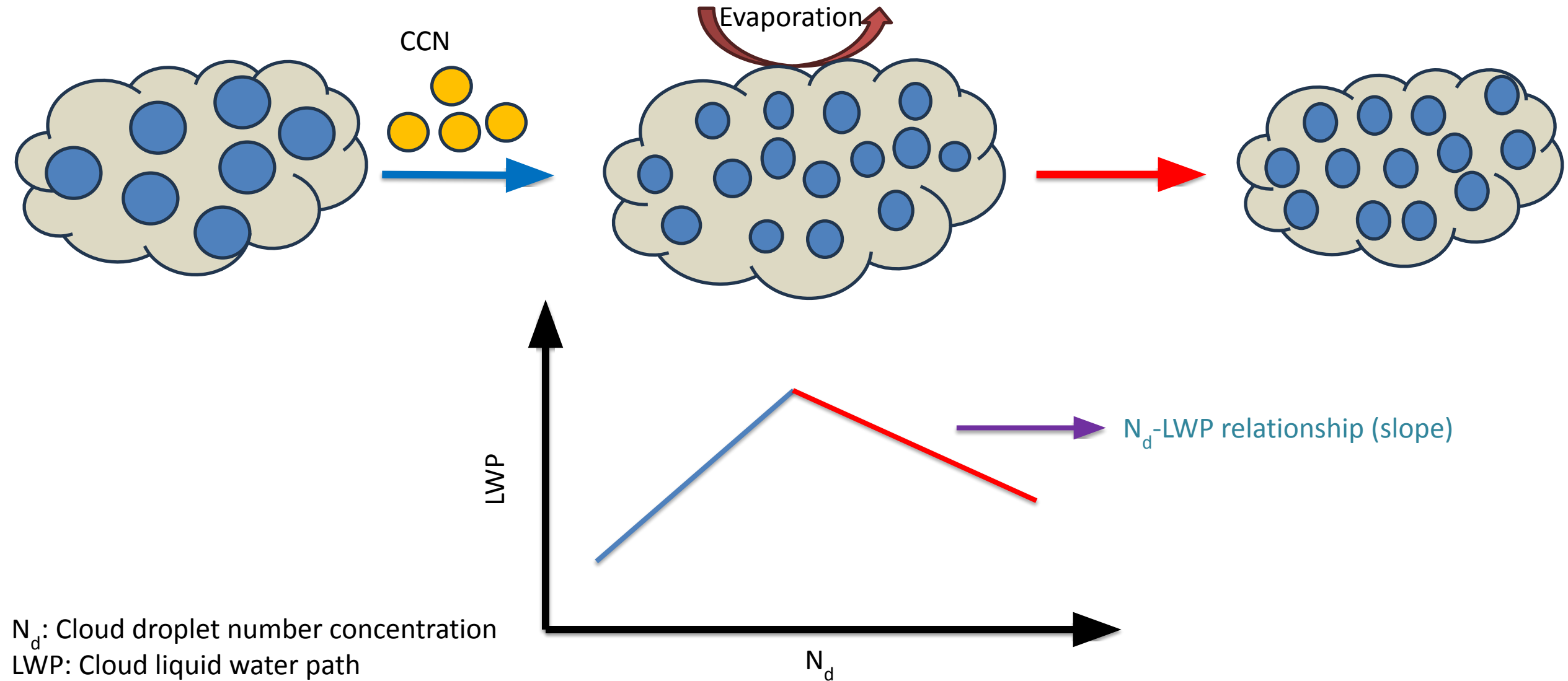
PPE (UKESM1)

Optimized constrained
(Regayre et al., 2023 constraint)

N_d -LWP slope constraint

-  Can PPE reproduce the N_d -LWP relationship?
-  Can we emulate this relationship and use it as constraint?
-  Can process-based constraints expose model structural errors?

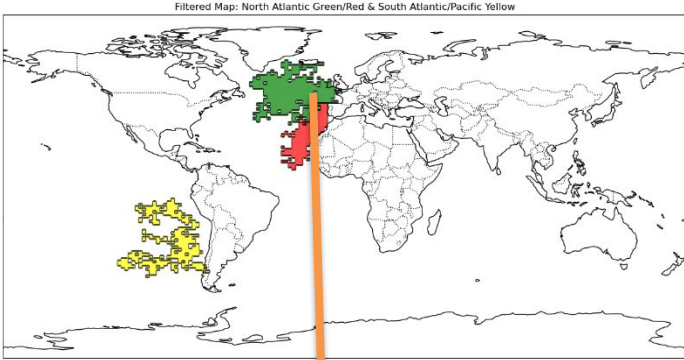
What is N_d -LWP relationship in the climate models?



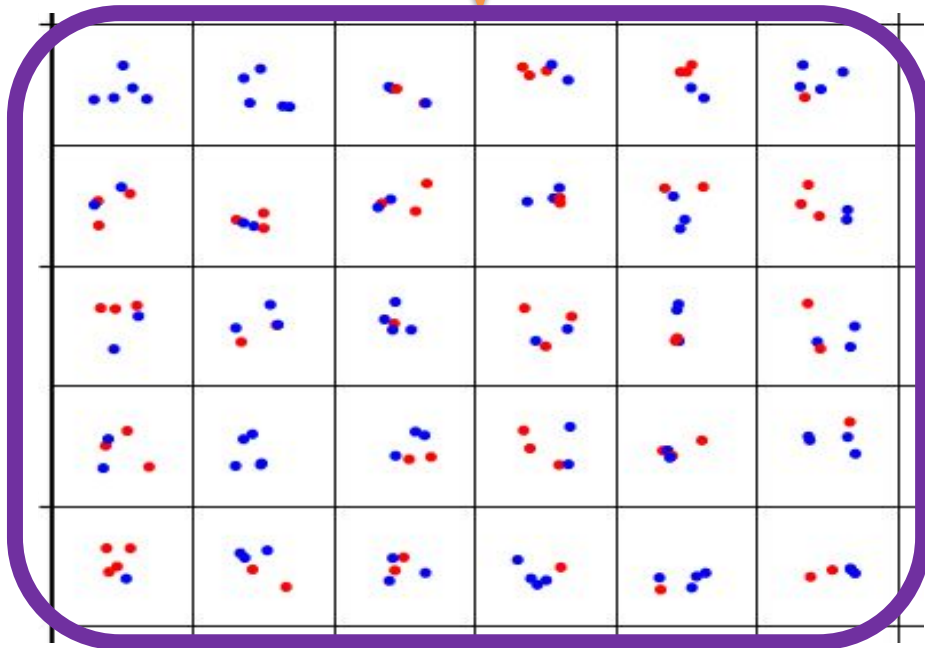
Calculation of the N_d -LWP slope



NA Cluster
monthly mean
for 2016-17



■ N_d
■ LWP

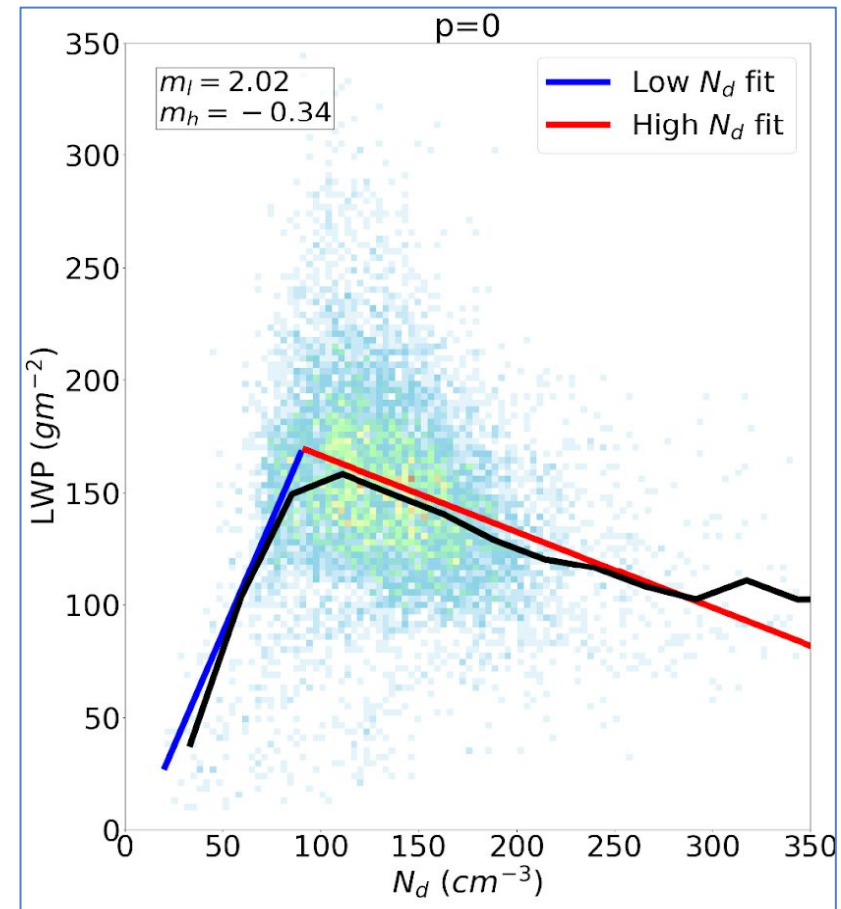


$$\ln L = \ln L^P + m_l (\ln N_d - \ln N_d^P)$$

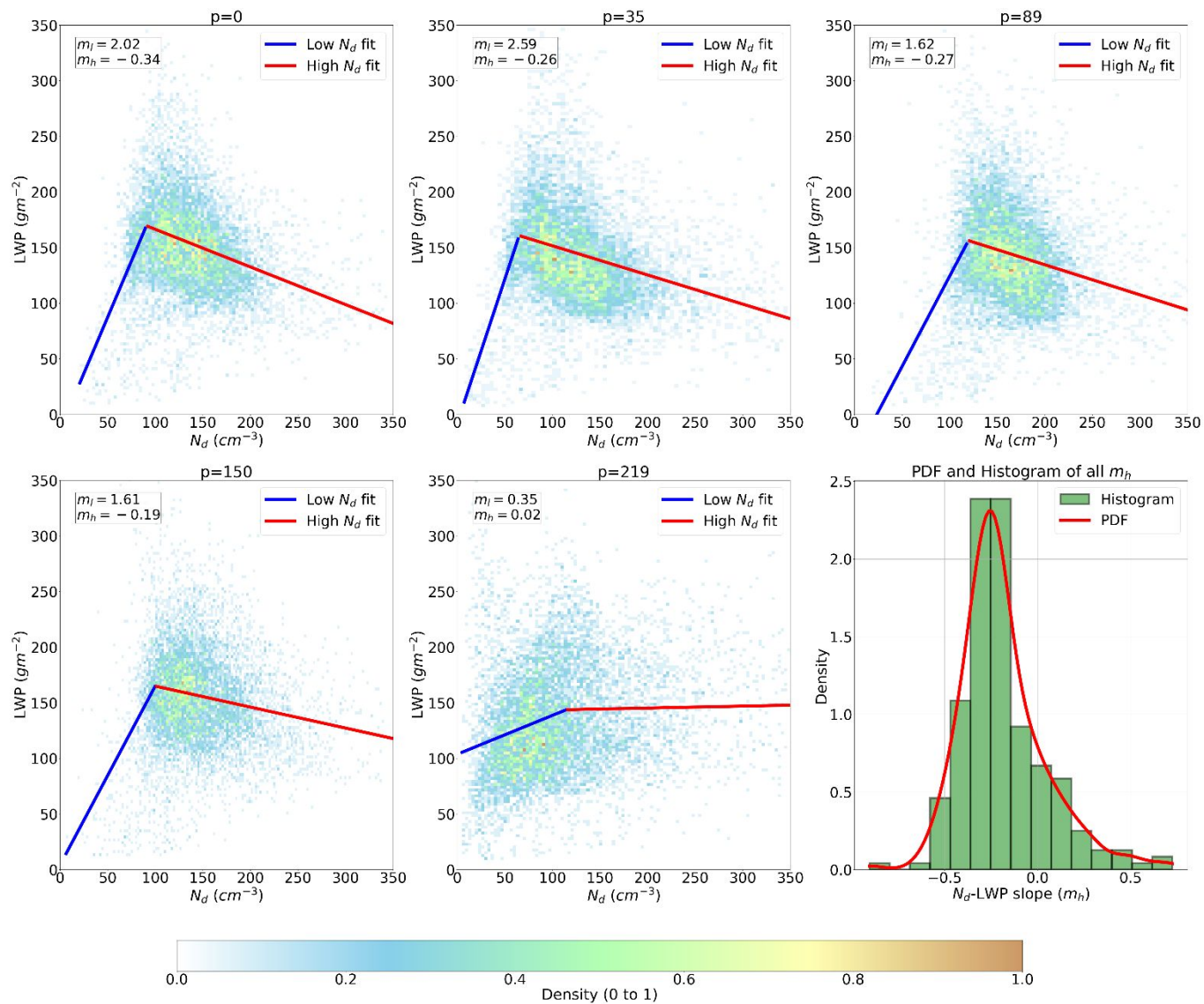
$$\ln L = \ln L^P + m_h (\ln N_d - \ln N_d^P)$$

$$N_d < N_d^P \quad \text{Gryspeerd et al., 2019 (1)}$$

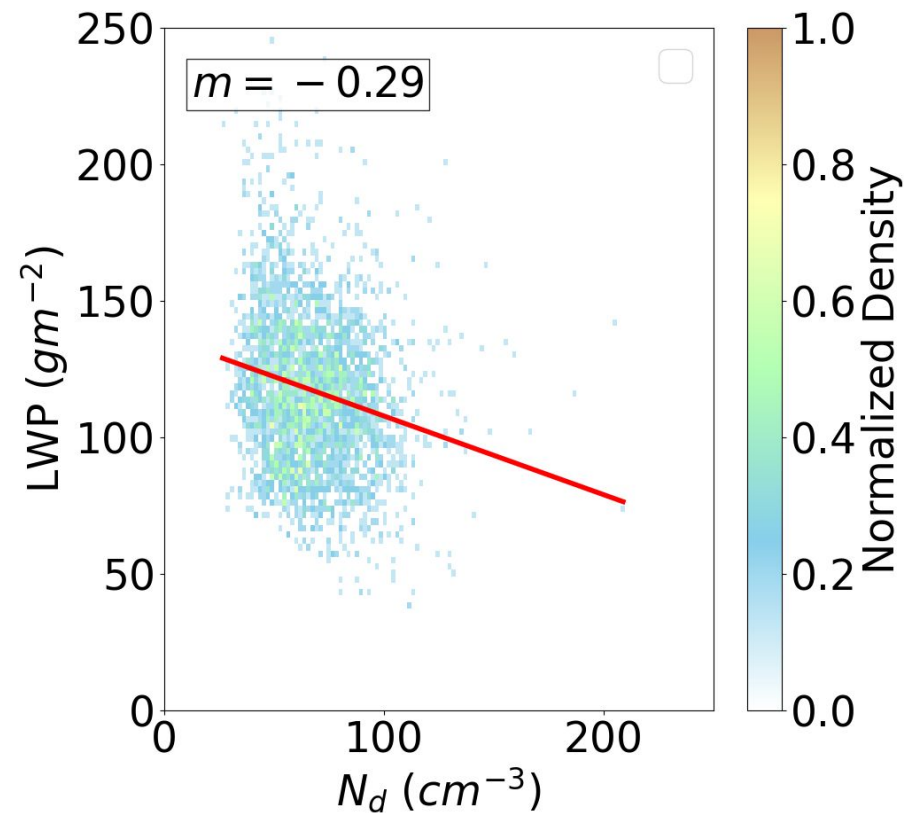
$$N_d \geq N_d^P$$



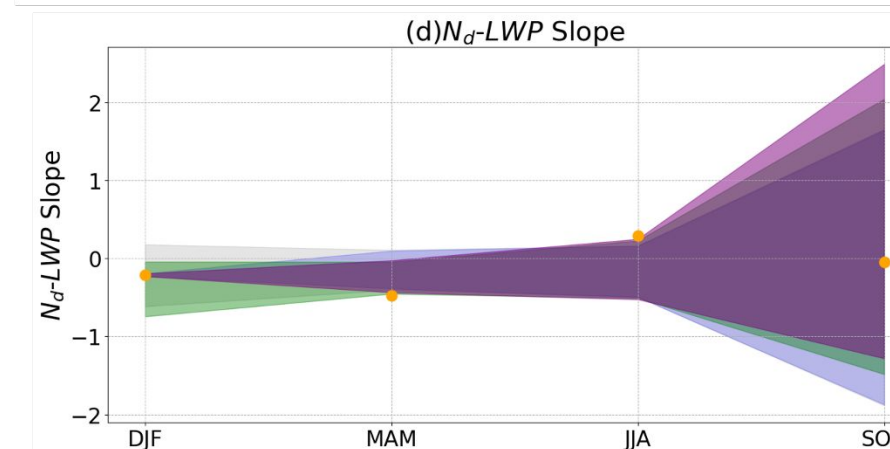
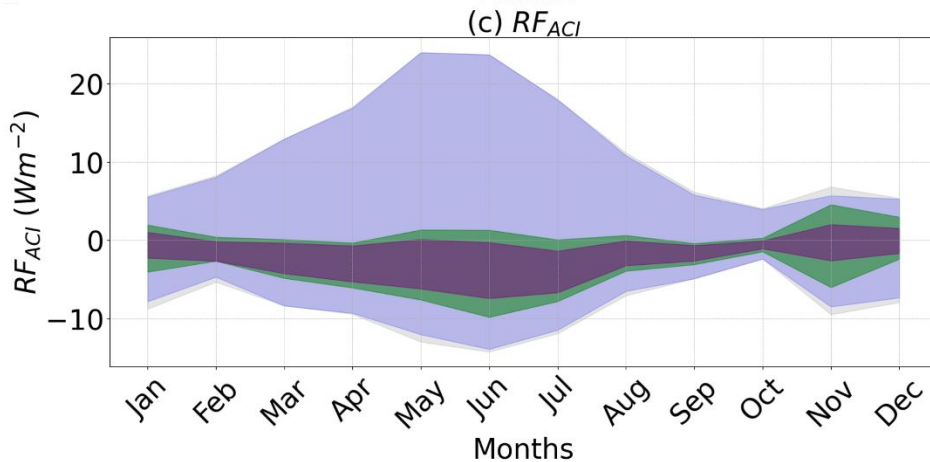
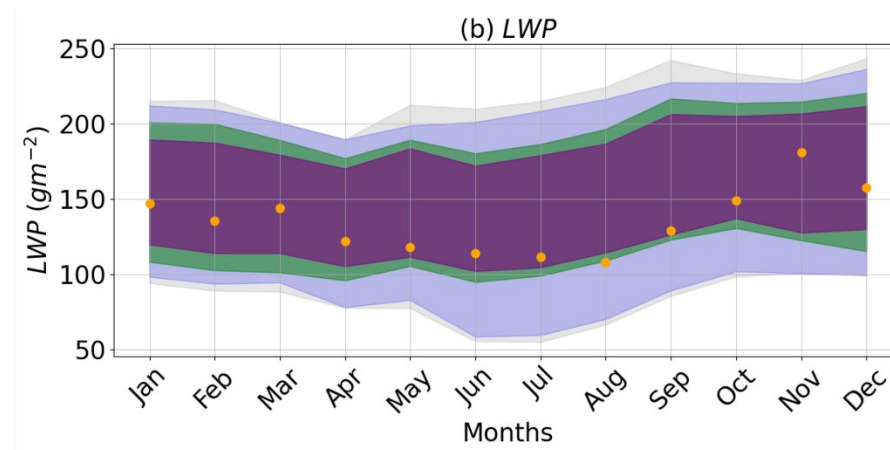
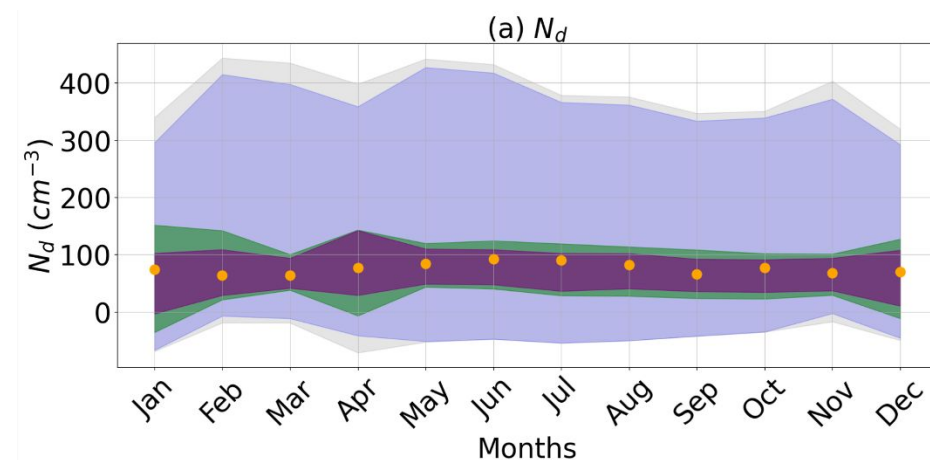
N_d -LWP slope from model data



N_d -LWP slope from satellite data

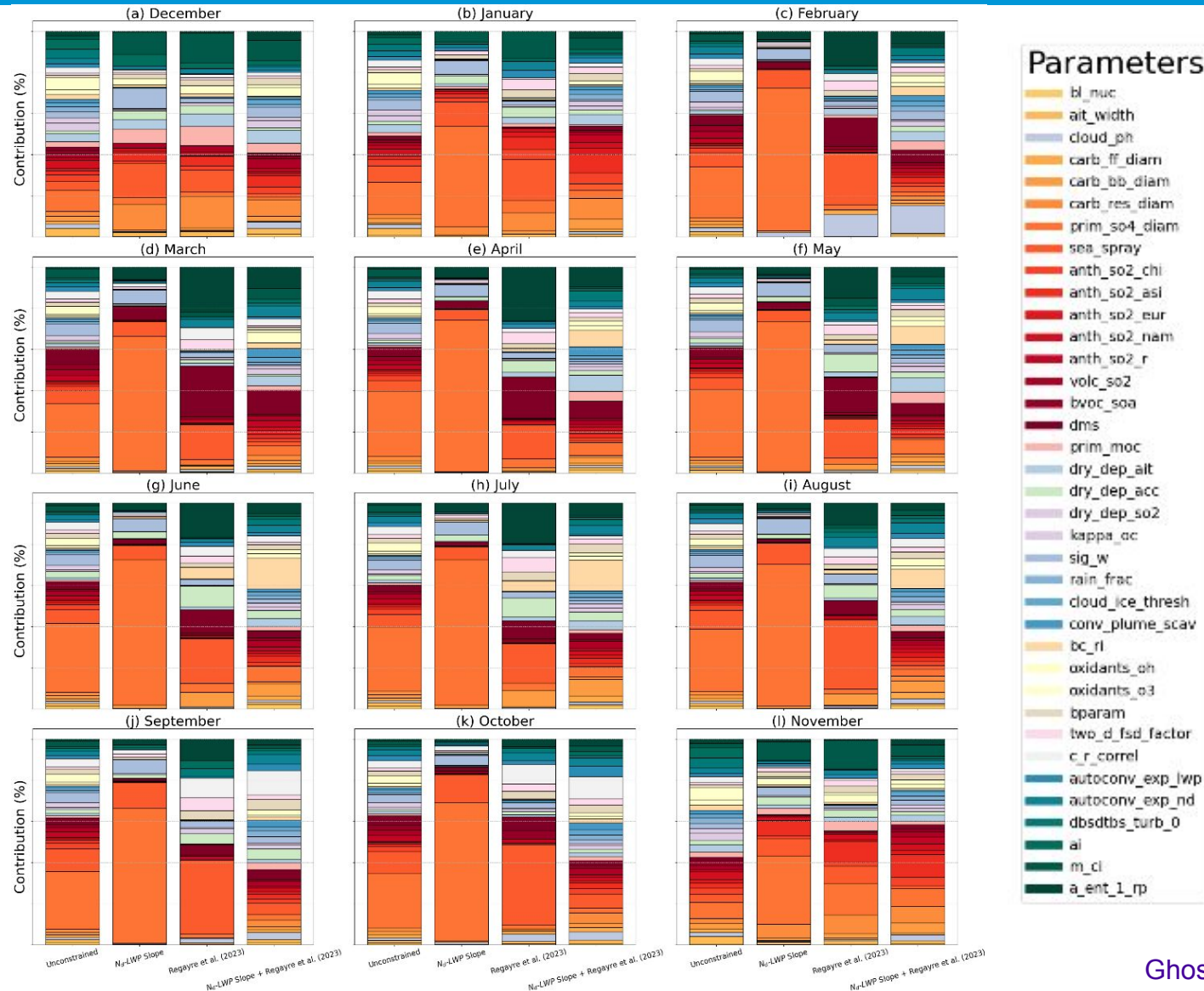


Performance of the N_d -LWP slope constraint

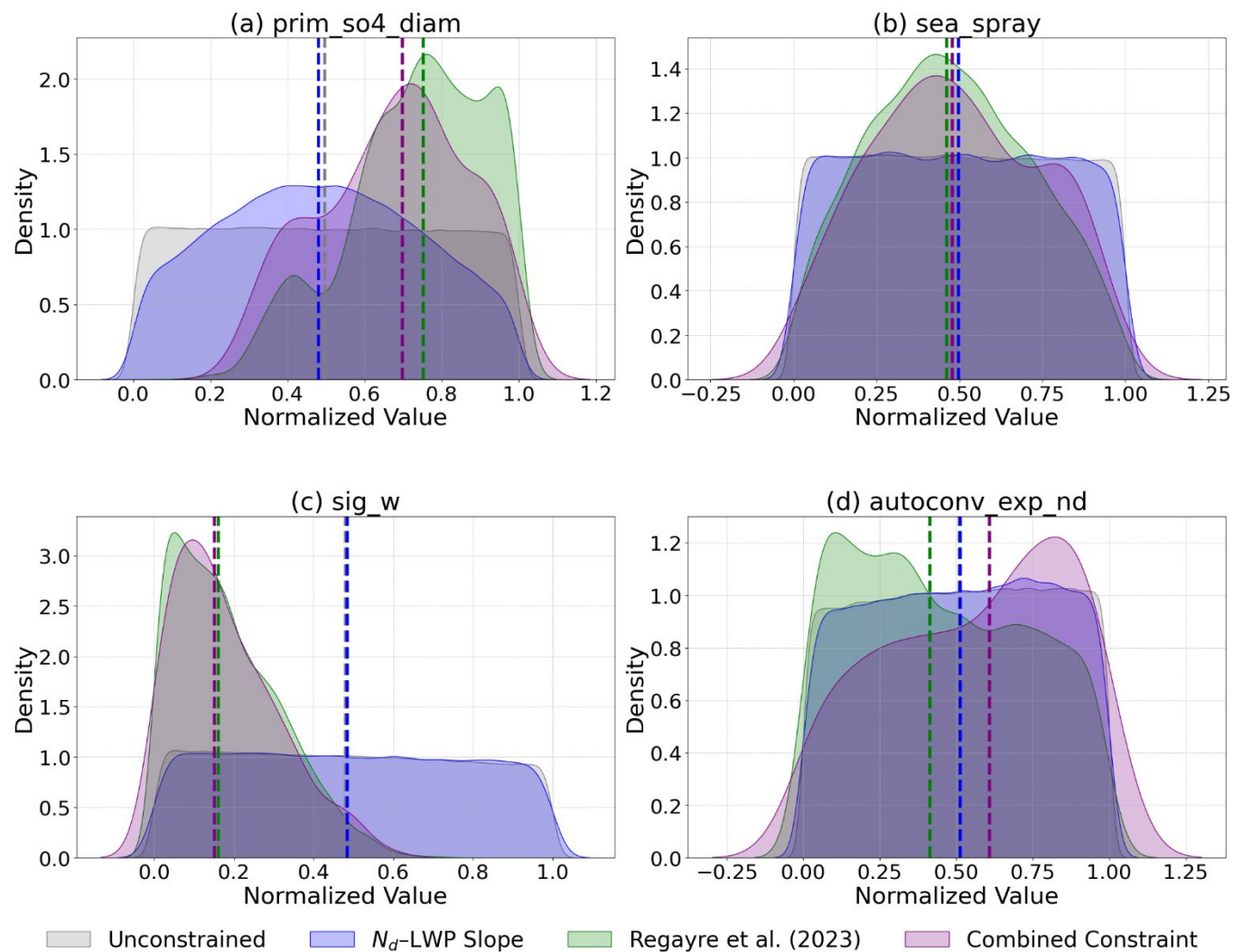


- Unconstrained
- N_d -LWP Slope Constraint
- Regayre et al. (2023) Constraint
- N_d -LWP Slope + Regayre et al. (2023) Constraint
- Observation

Sensitivity analysis of input parameter ERF_ACI



Selected input parameter pdf



Does our PPE produce any meaningful relationships?

Yes, PPE results show that we can obtain some N_d -LWP relationships from the model output.

Can we emulate these relationships and use them as constraints?

Yes, we successfully emulate them and use them as an additional constraint to further reduce RF_ACI uncertainty. However, they cannot be used as a single constraint due to model structural errors.

Using process-based constraints, can we expose model structural errors?

It may indicate a missing link between aerosol processing-related parameters and cloud processing-related parameters, which can be further investigated.

Use this N_d -LWP relationship-based approach for other clusters to reduce RF_ACI uncertainty, particularly for clusters that remain more uncertain after applying the optimal constraint.

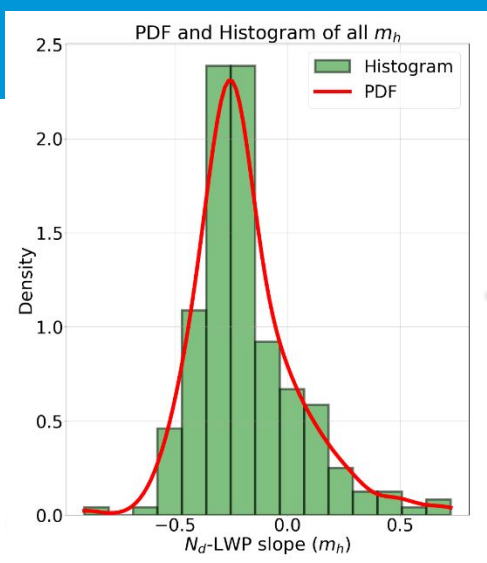
Potentially expose more model structural errors through inter-cluster analysis

Analyze the N_d -LWP relationship-based approach in a multi-model setup.

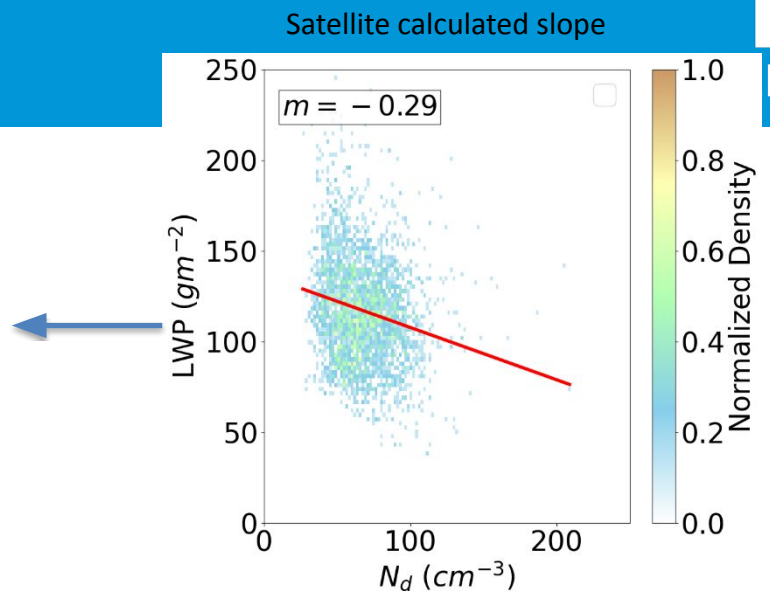
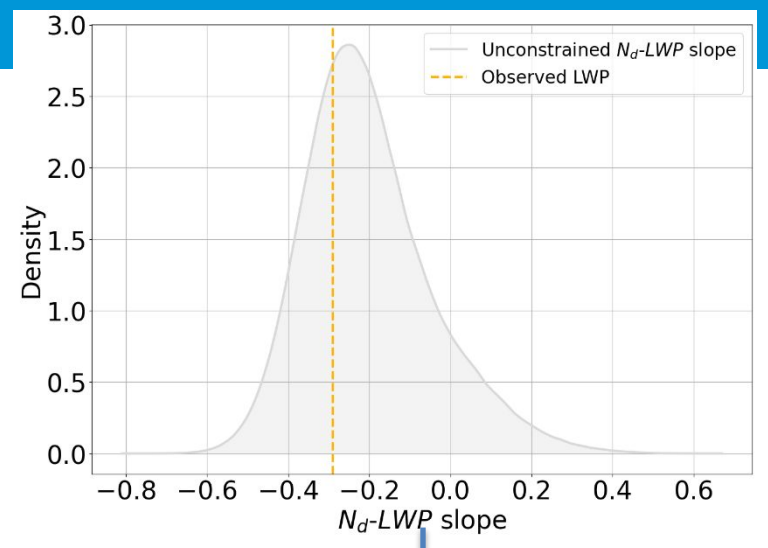


Thank you!

Questions?



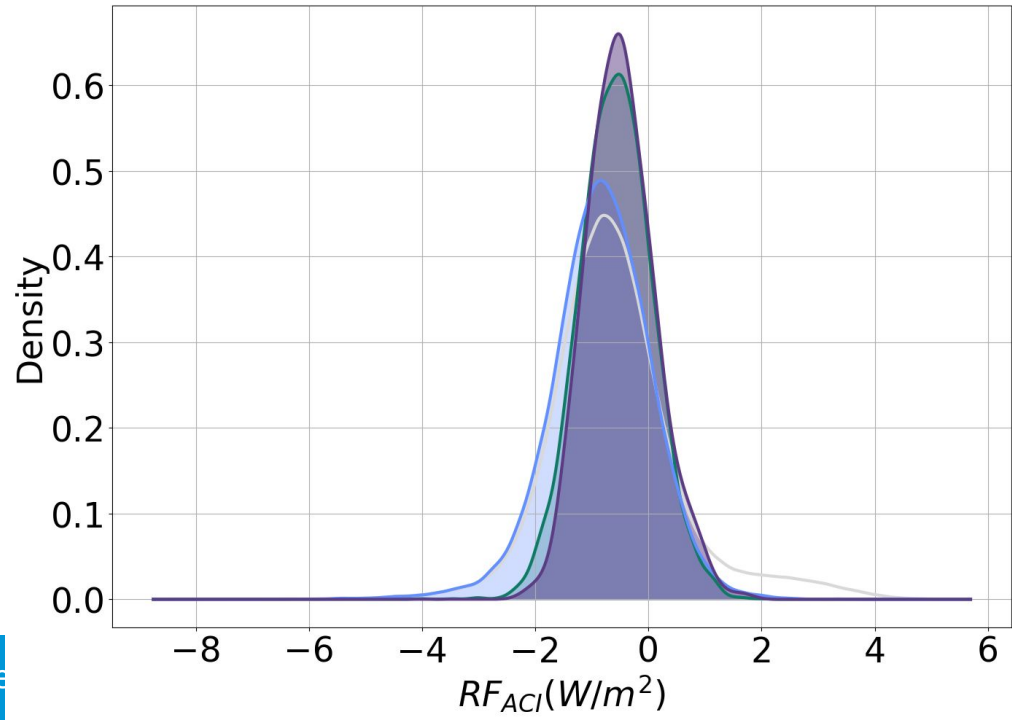
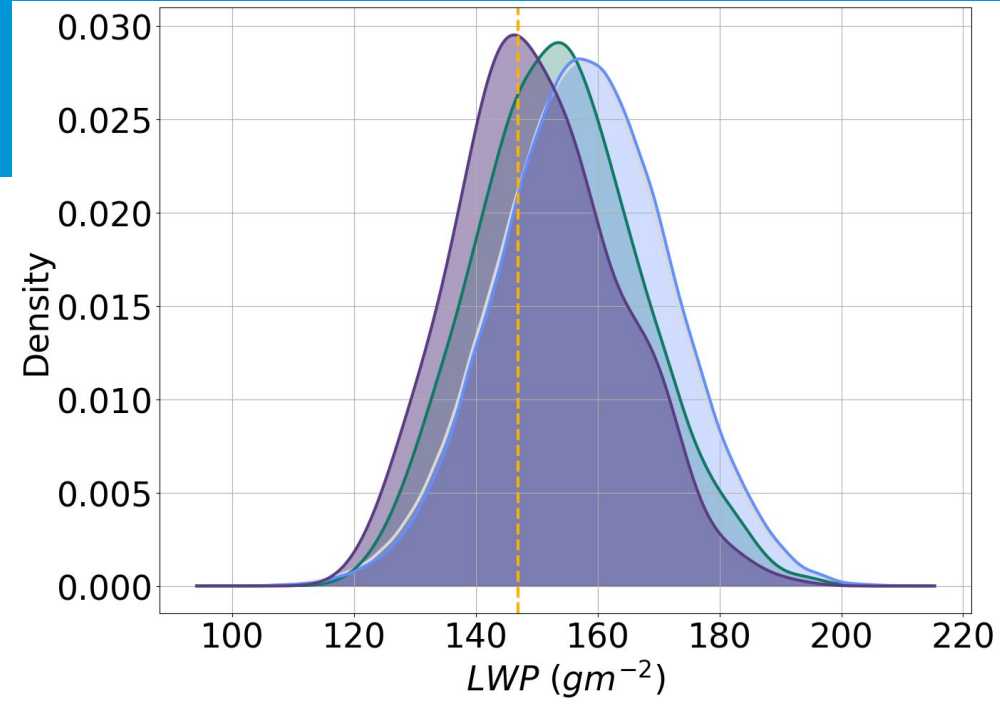
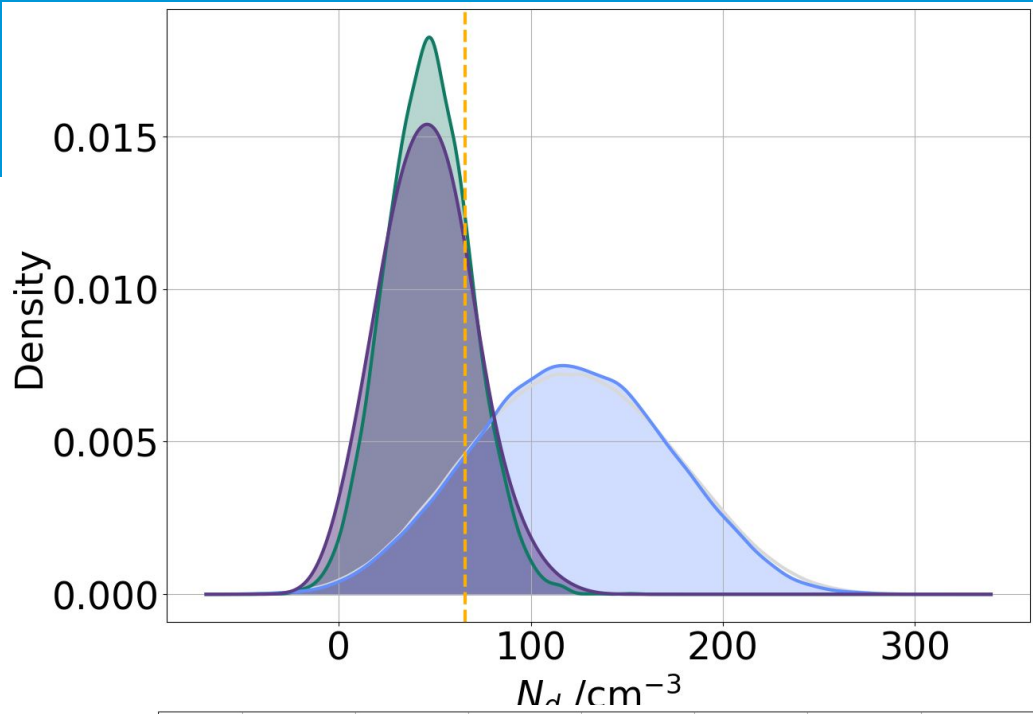
Emulation



Nd-LWP slope constraint (108700)

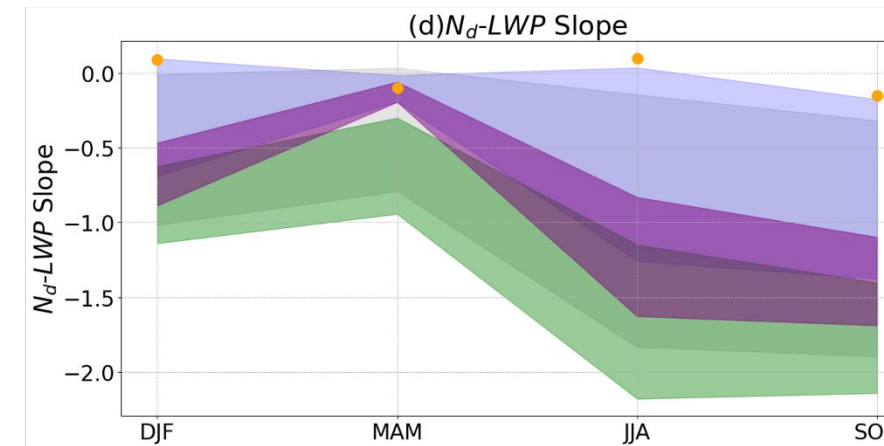
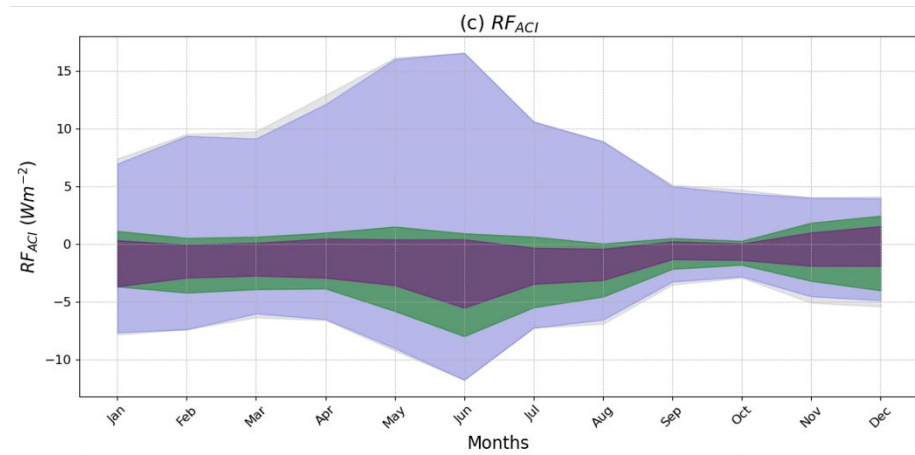
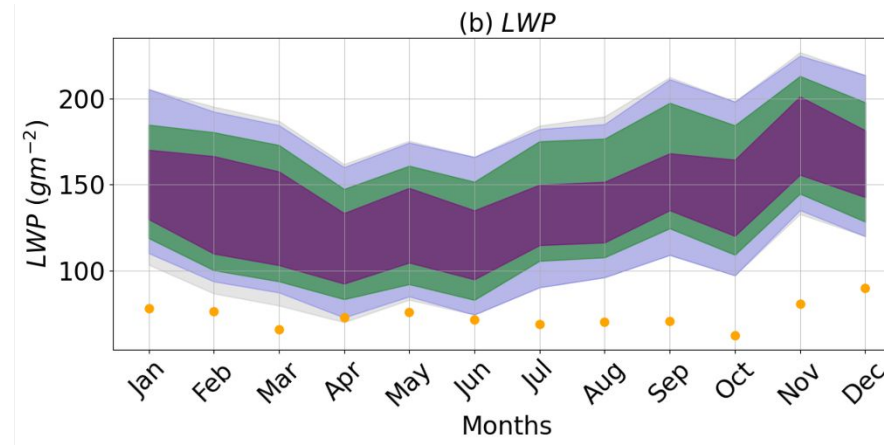
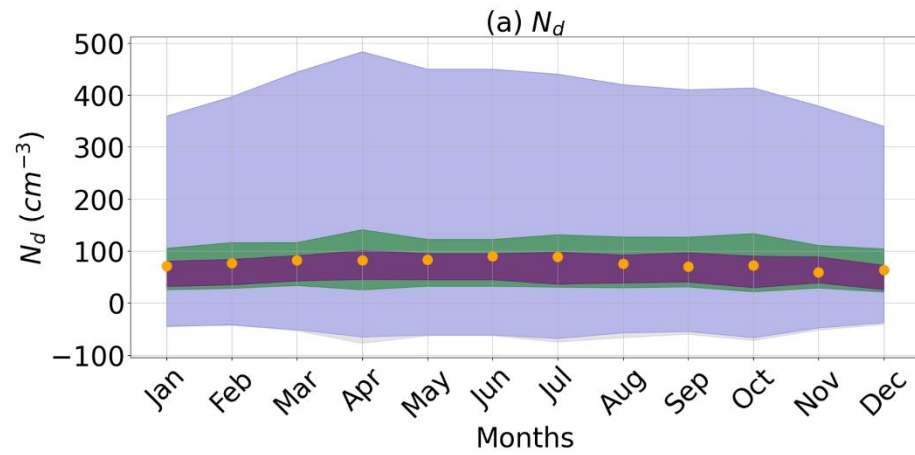
(Regayre et al., 2023 constraint)
(5000)

Regayre et al., 2023 + Nd-LWP
slope constraint (927)



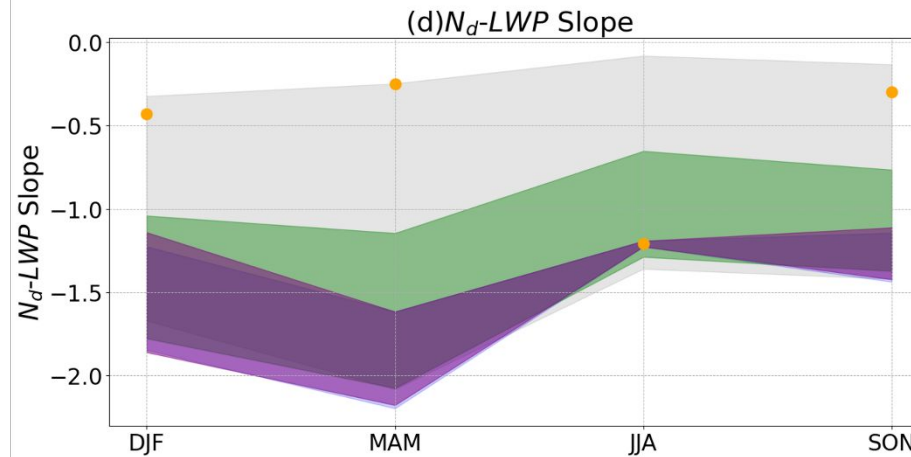
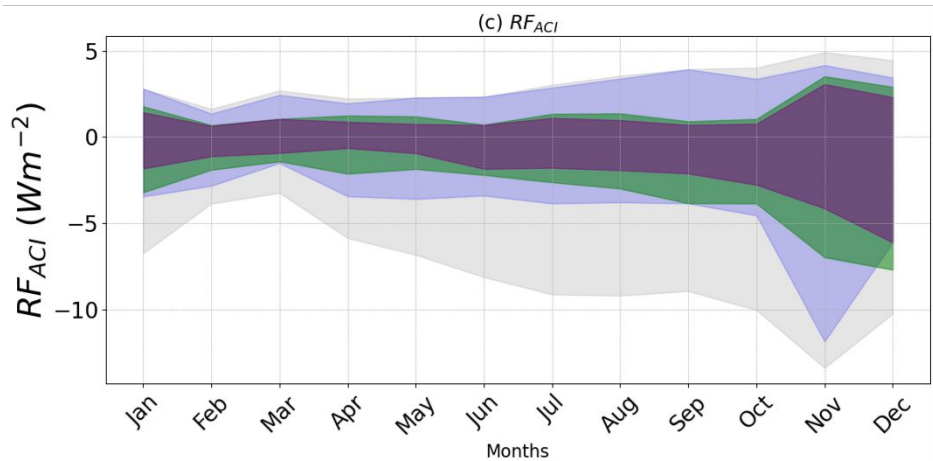
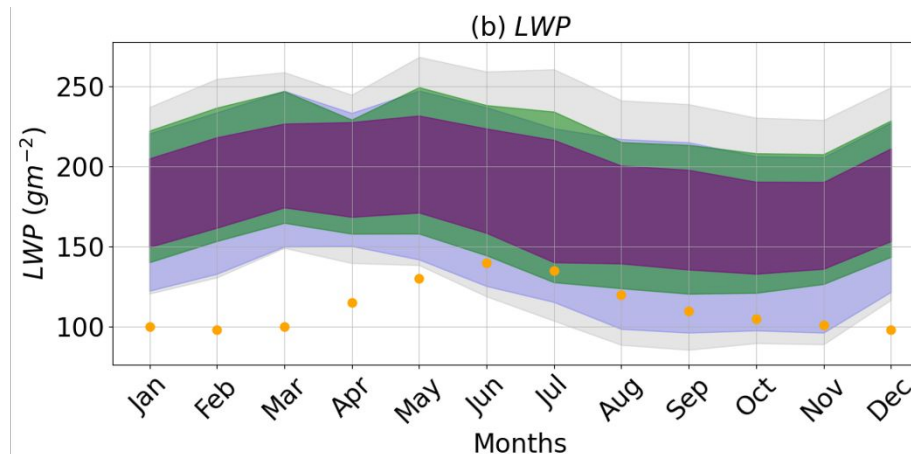
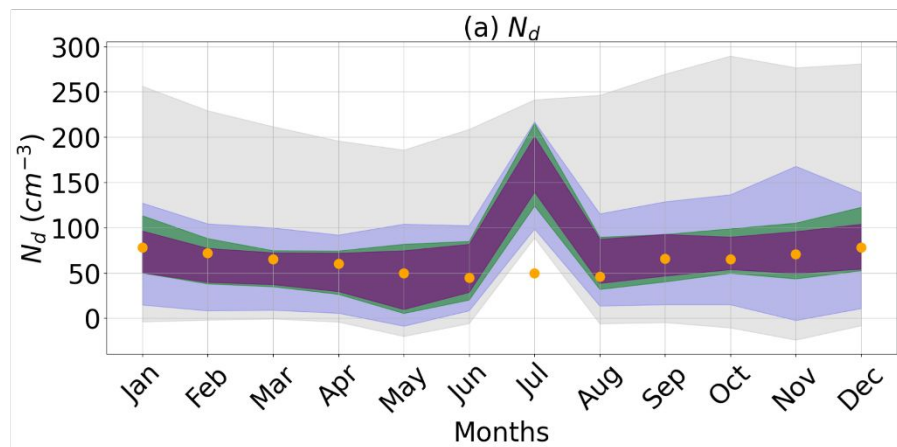
- Unconstrained
- Regayre et al. (2023) Constraint
- N_d -LWP slope constraint
- N_d -LWP slope + Regayre et al. (2023) constraint
- - - Observation

Performance of the N_d -LWP slope constraint



- Unconstrained
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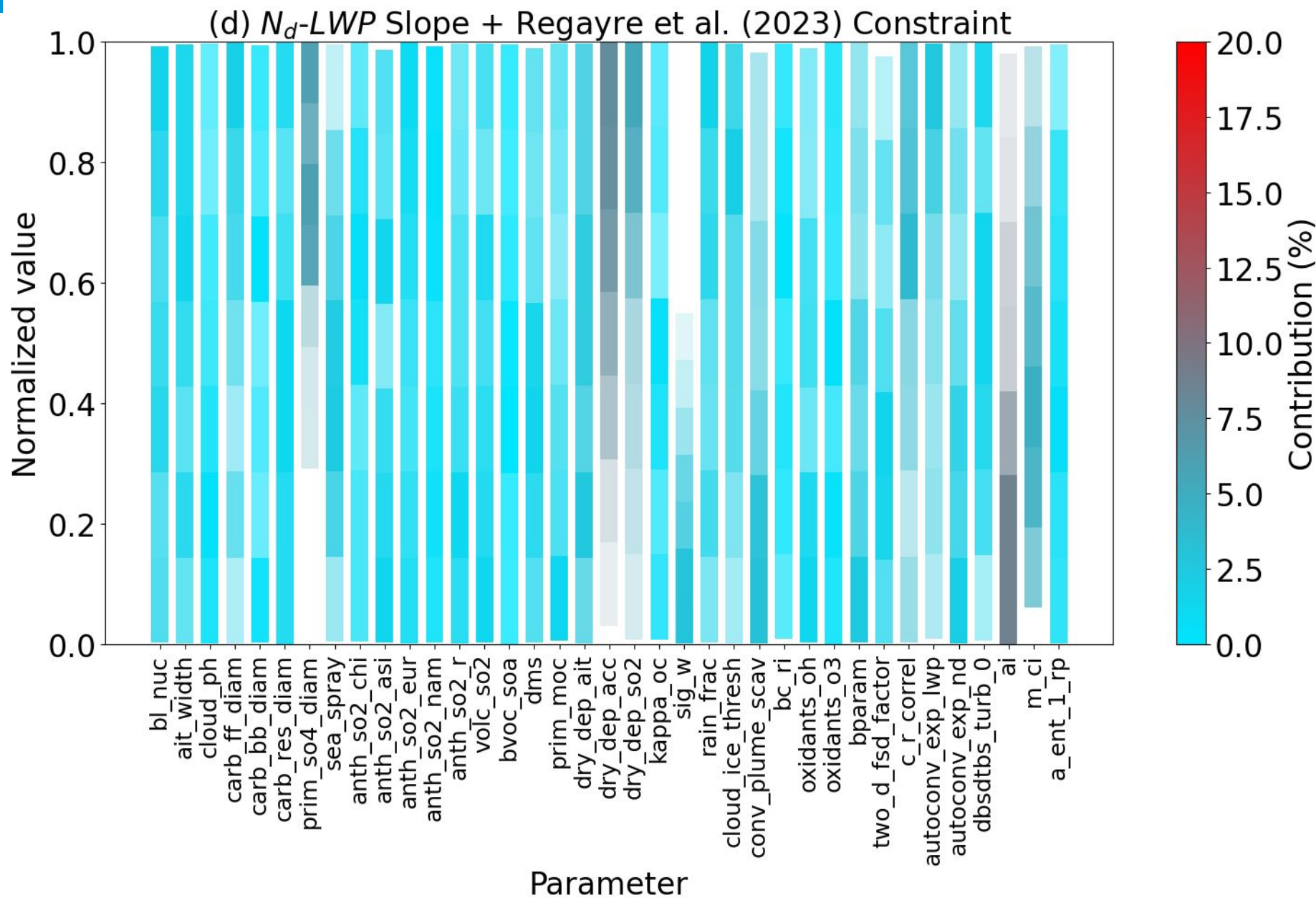
Sensitivity analysis of input parameter

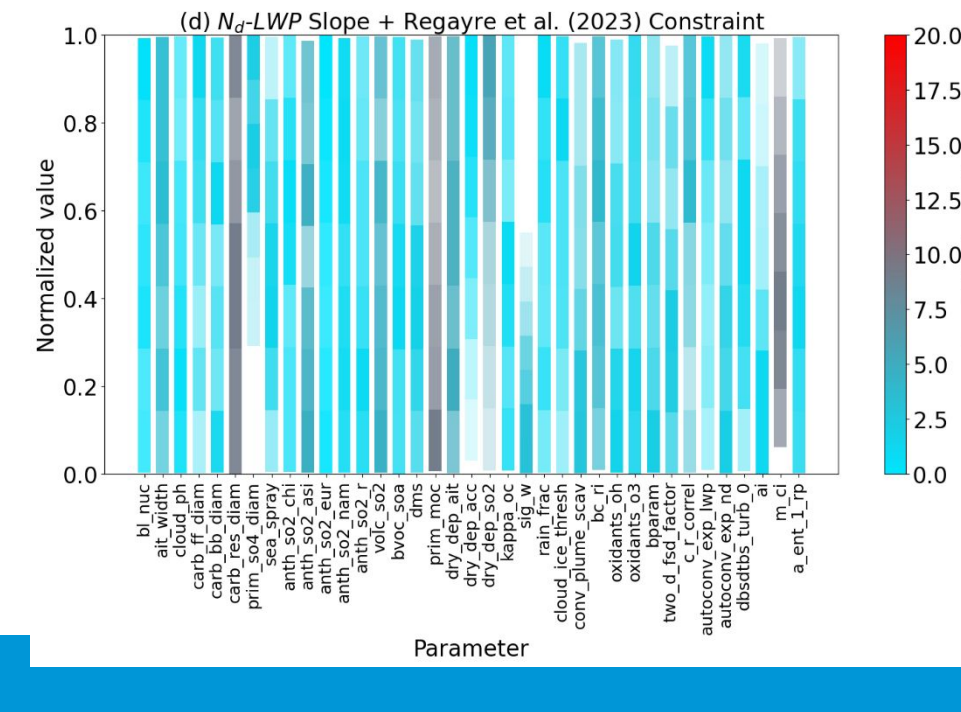
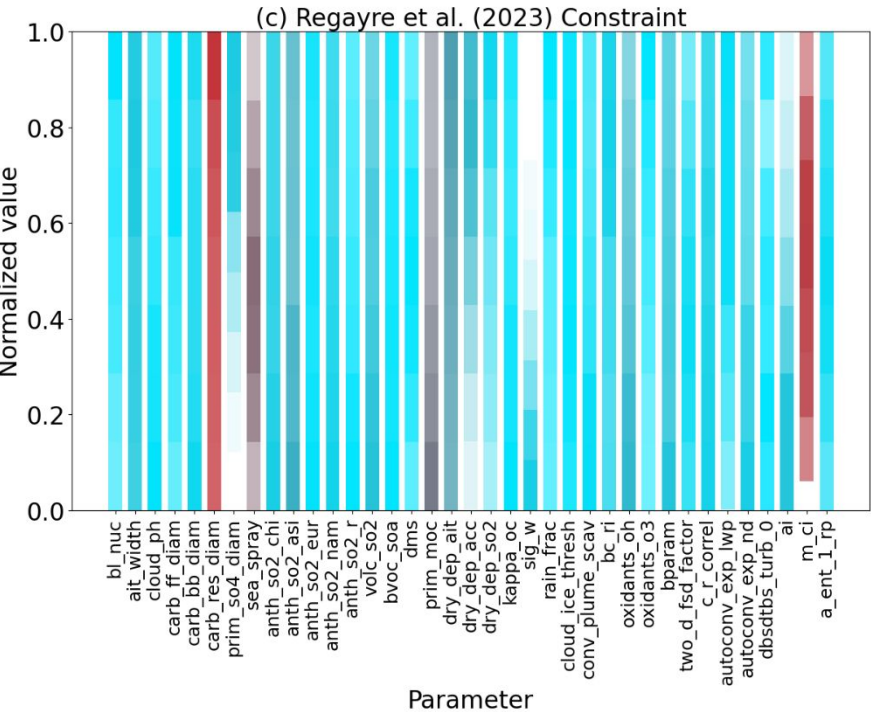
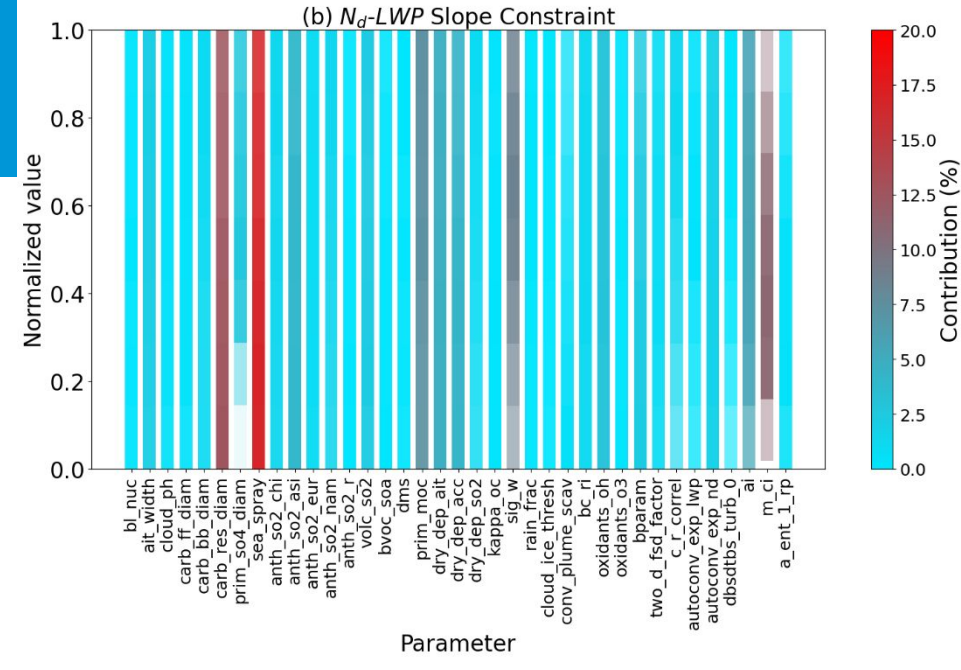
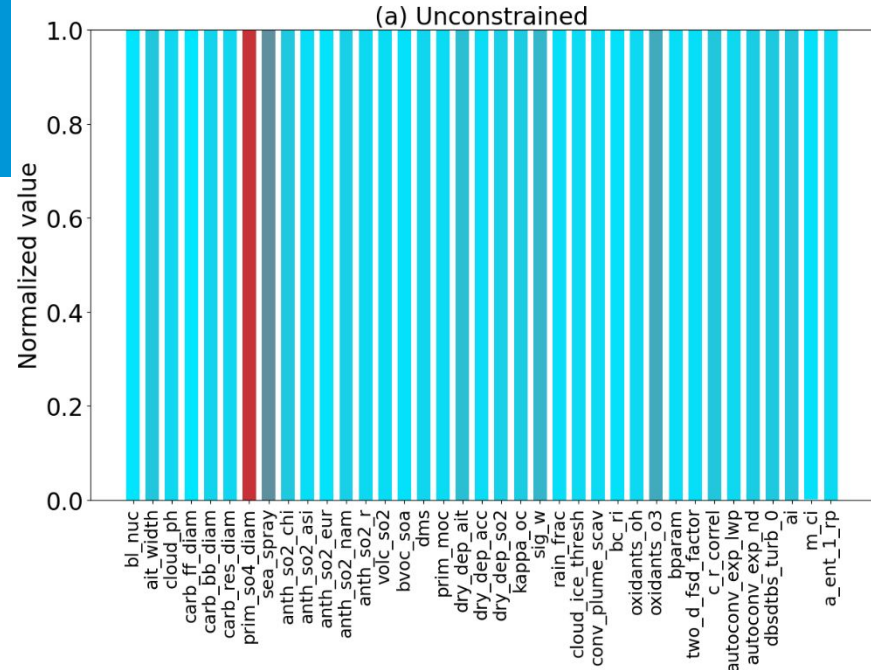


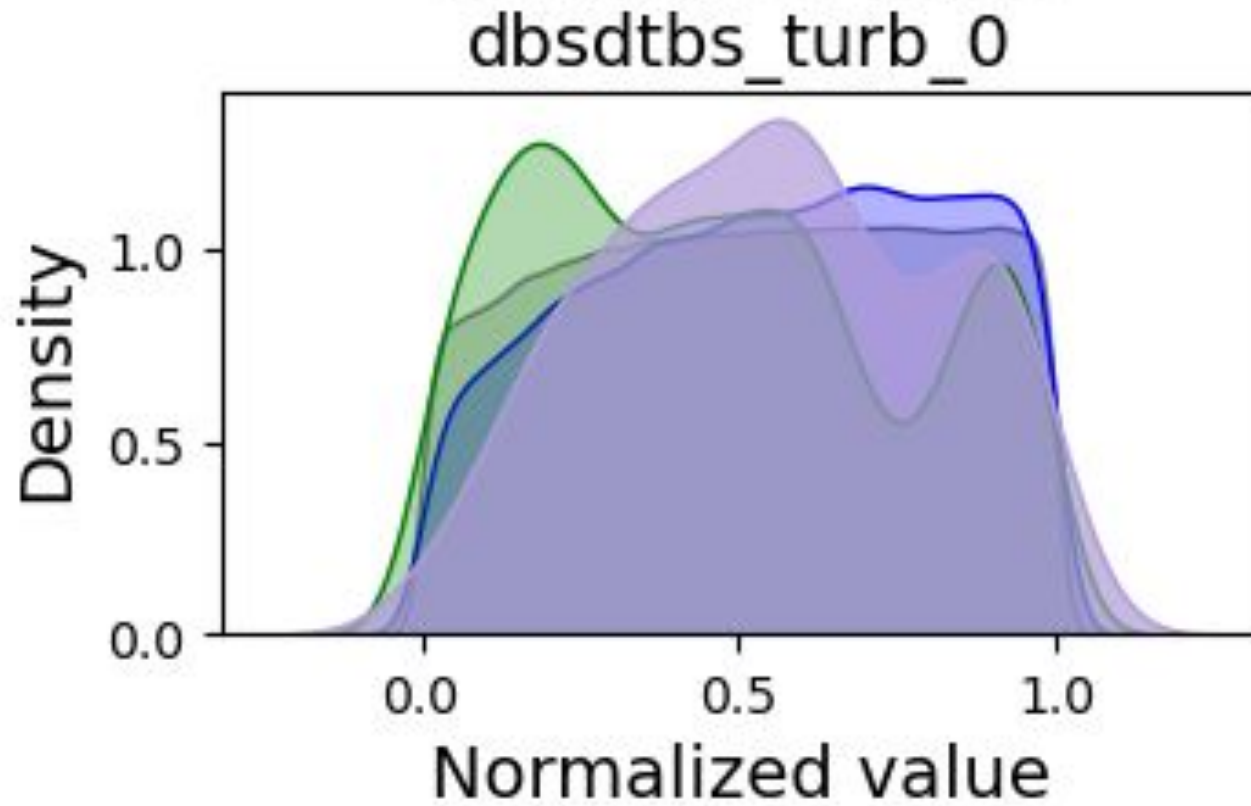
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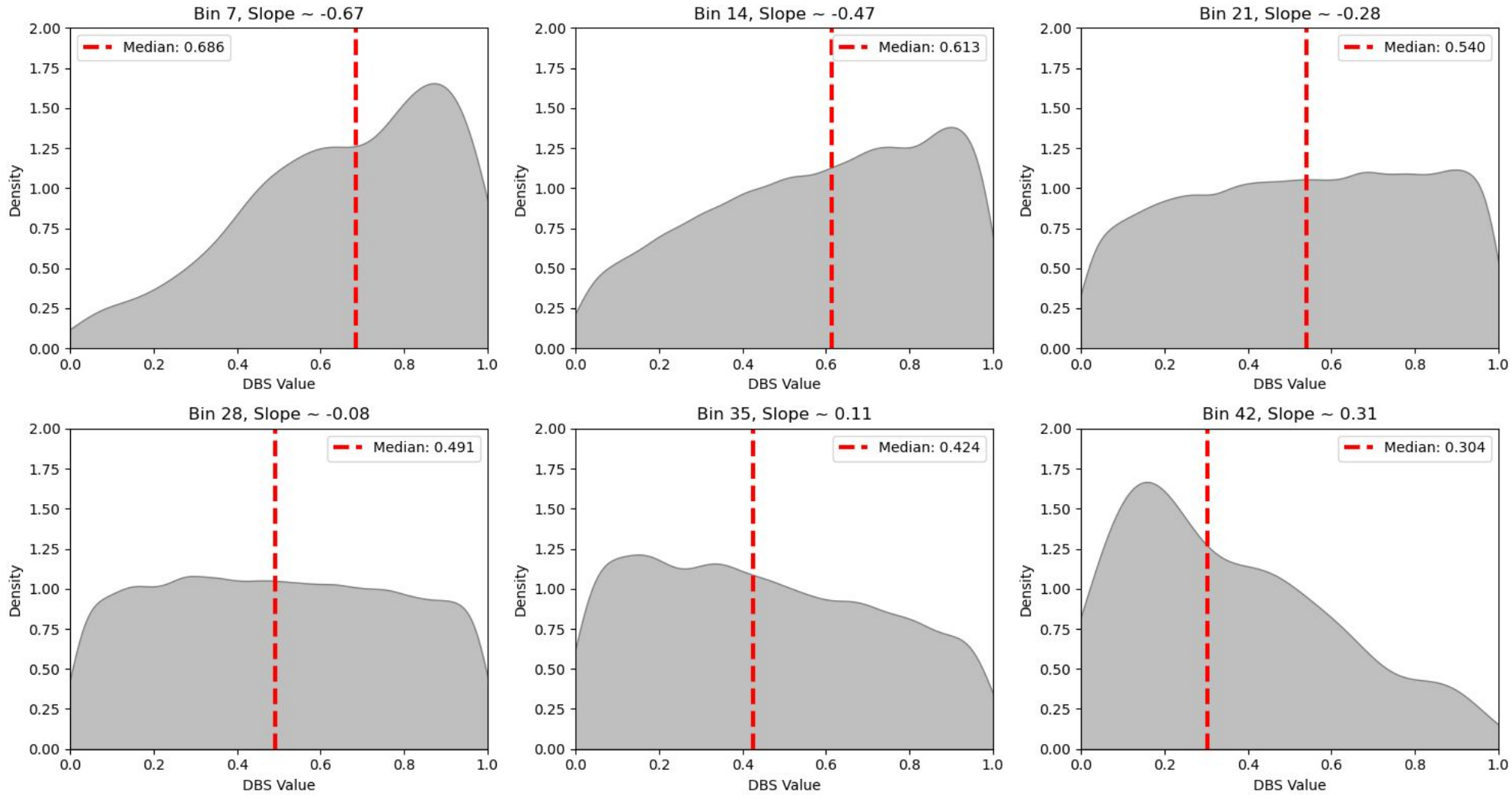


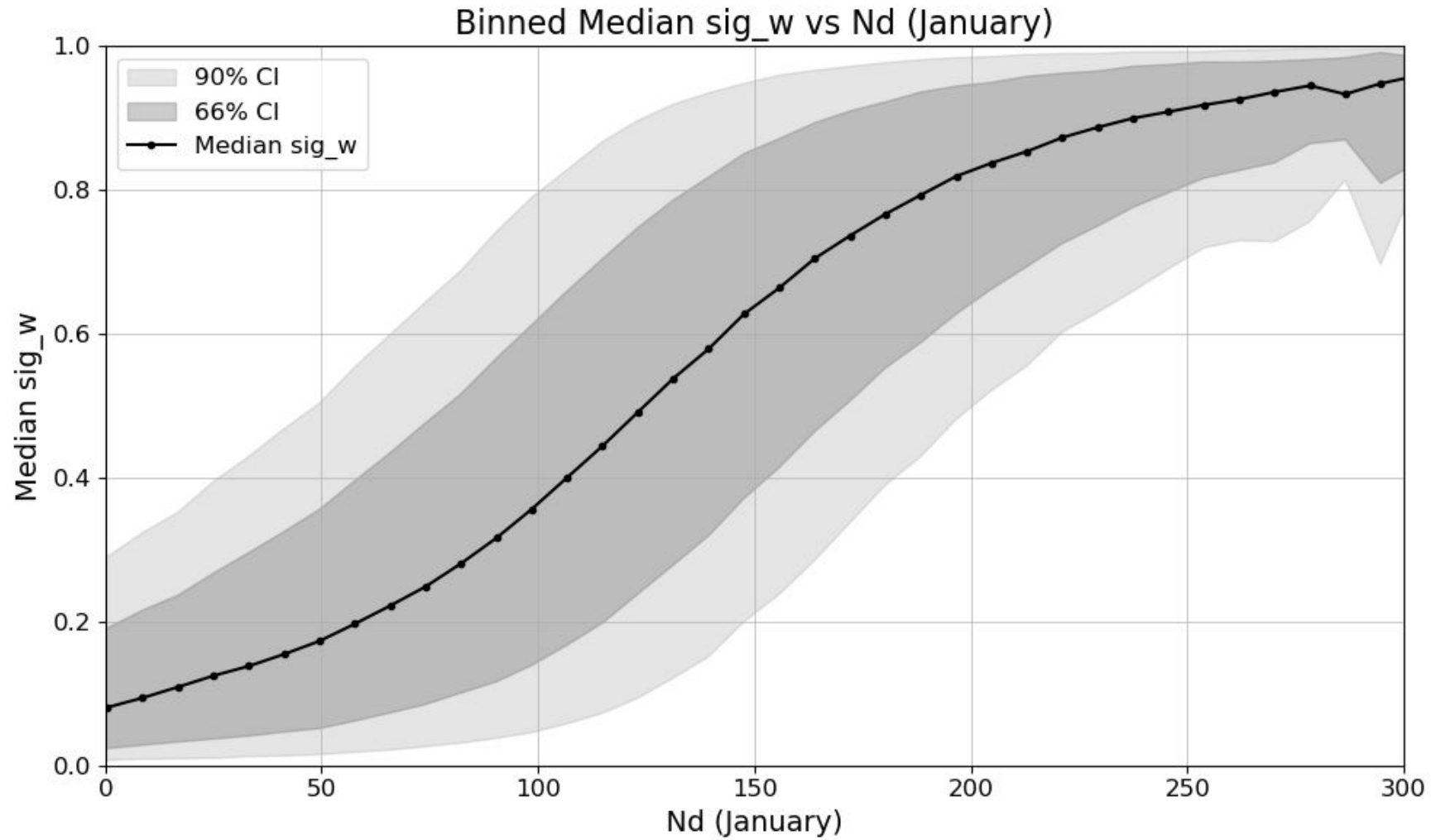




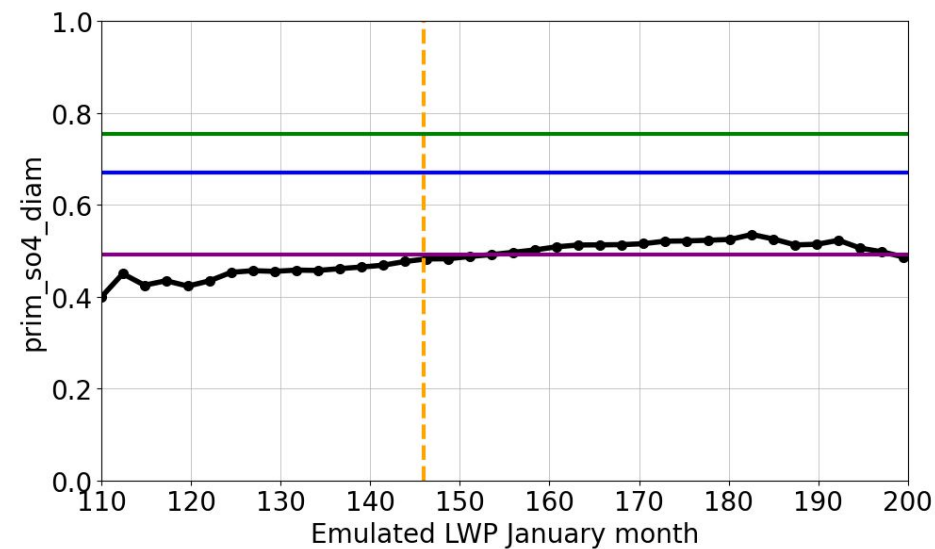
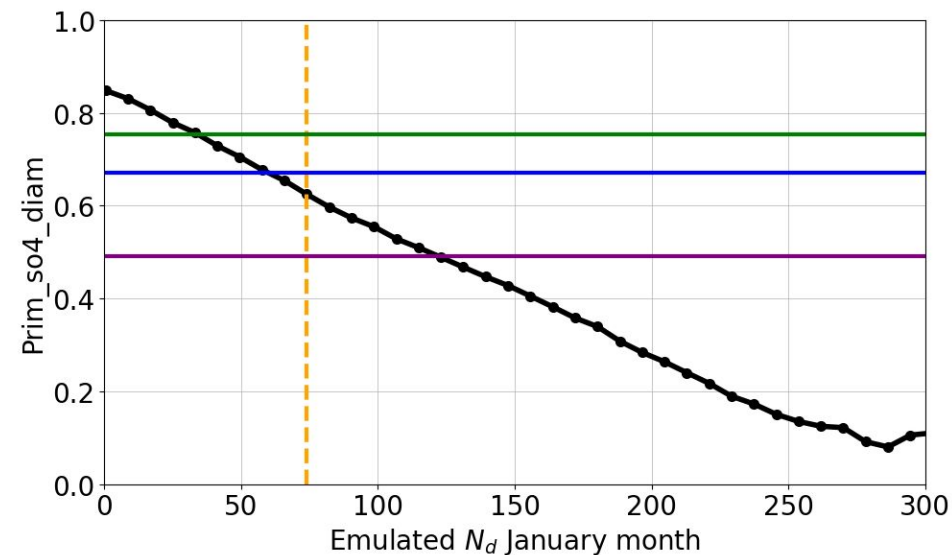
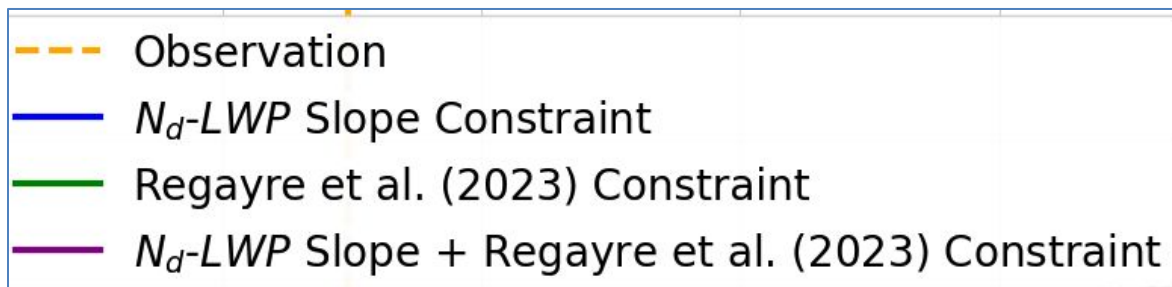
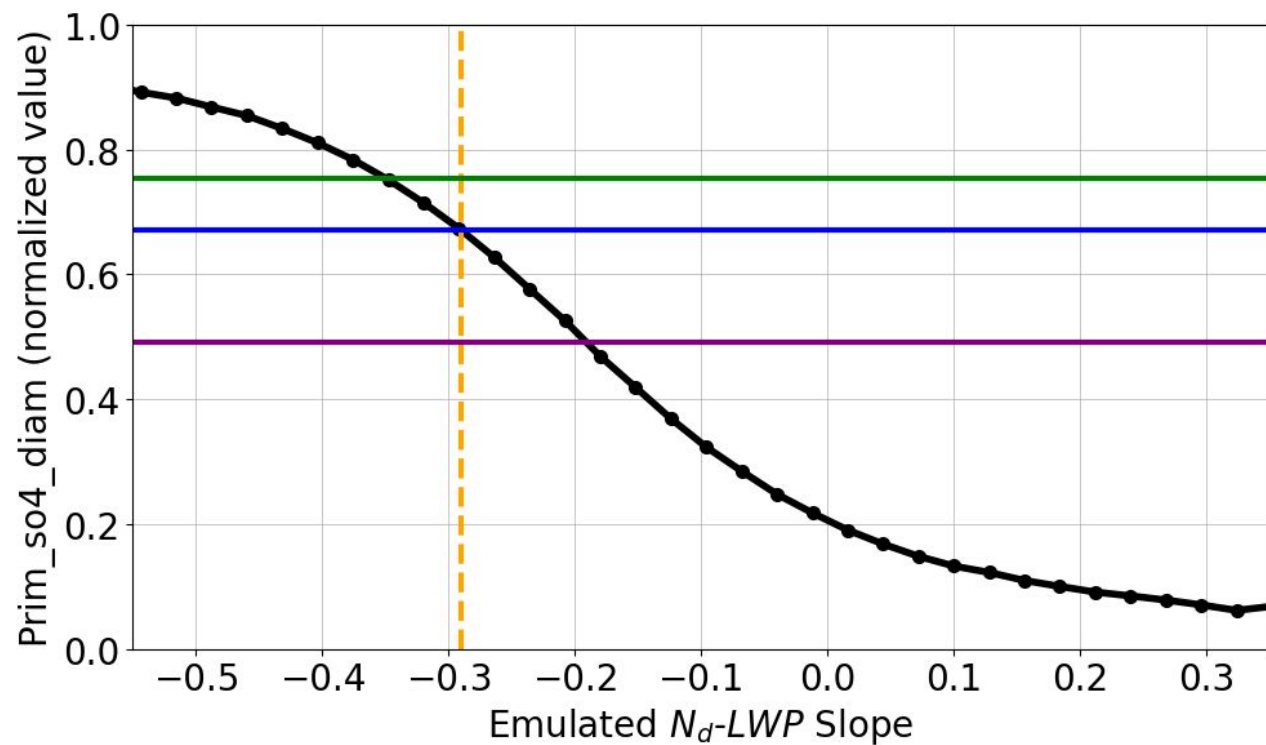


Unconstrained N_d -LWP slope constraint Regayre et al. (2023) constraint N_d -LWP slope + Regayre et al. (2023) constraint

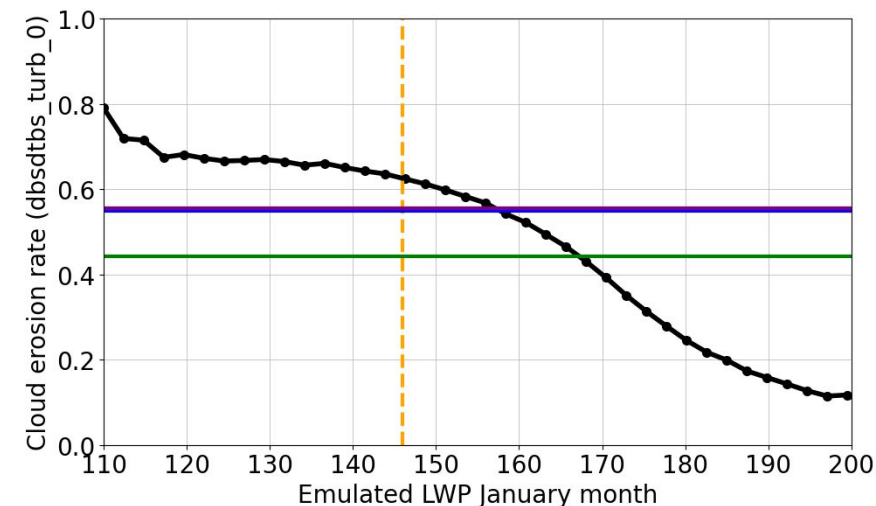
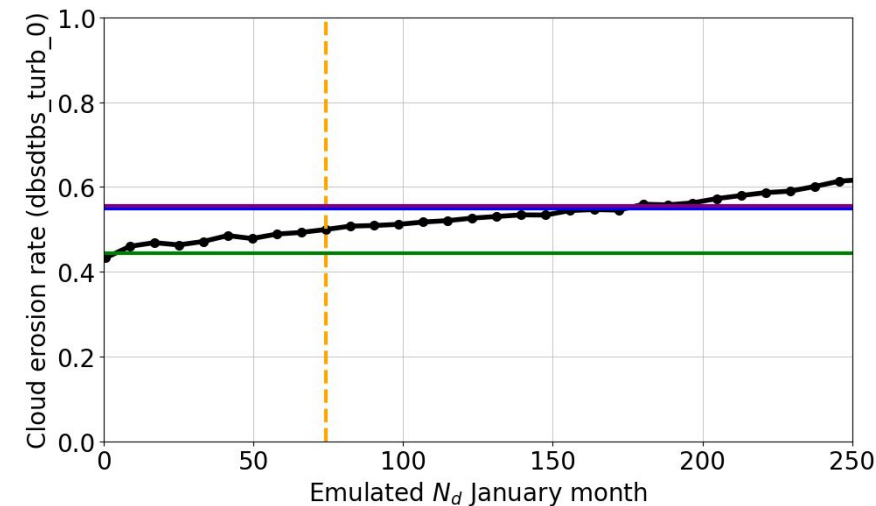
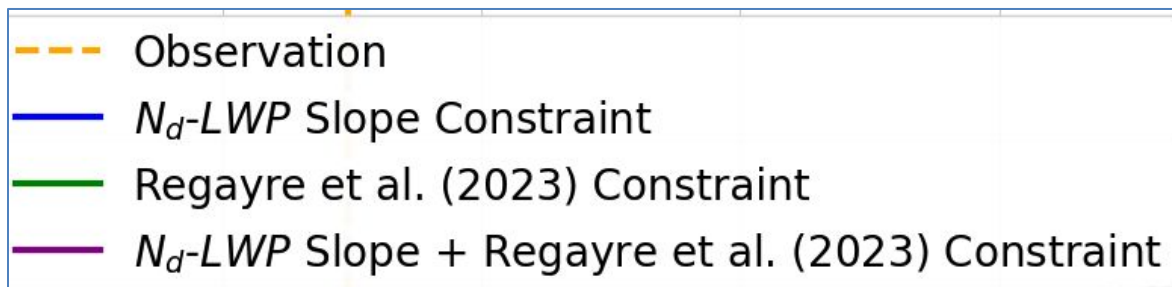
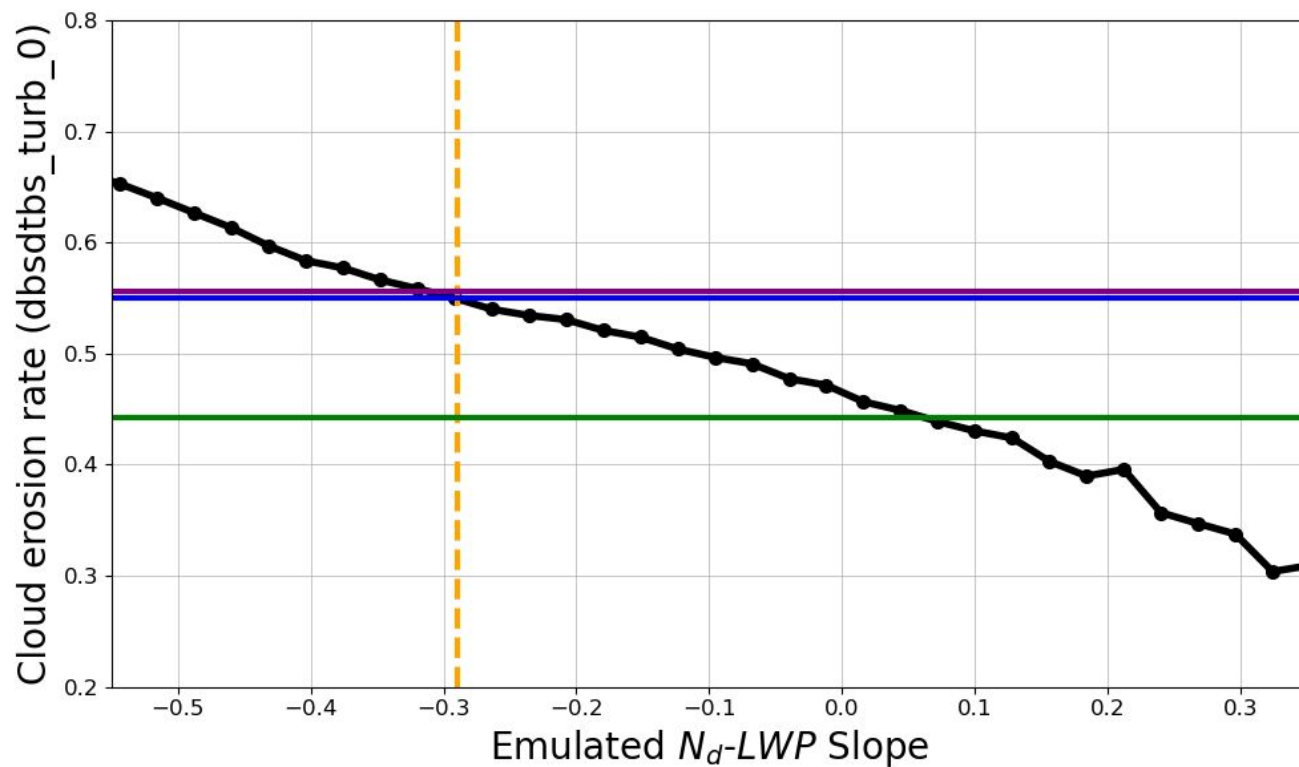




Prim_SO4_diam sensitivity to N_d -LWP slope



Cloud erosion sensitivity to N_d -LWP slope



Updraft sensitivity to N_d -LWP slope

