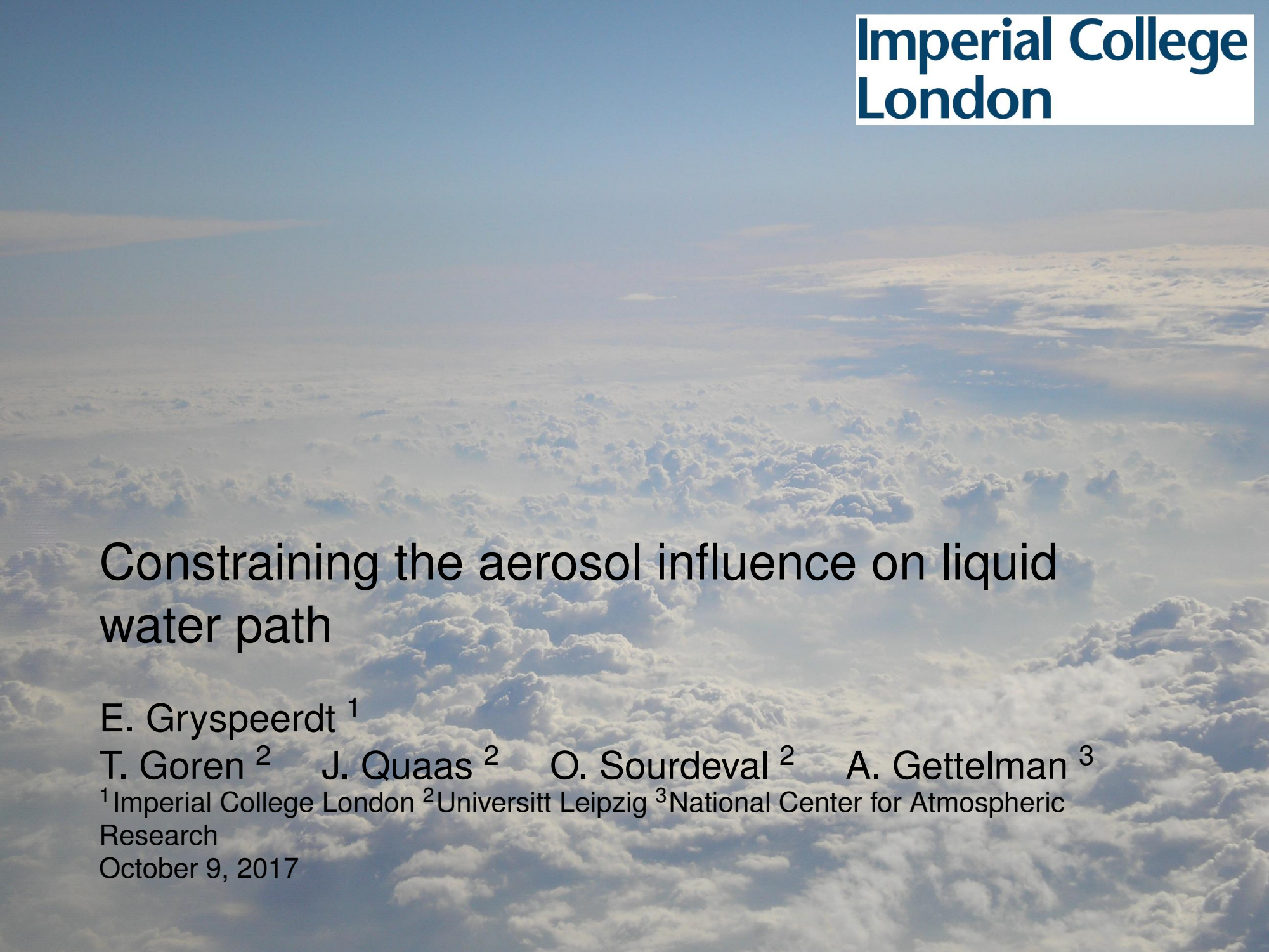


Constraining the aerosol influence on liquid water path

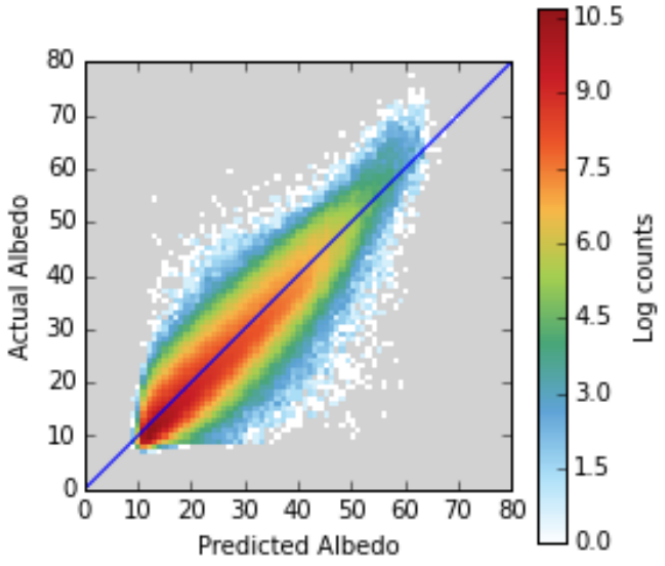
E. Gryspeerdt [1]
T. Goren [2] J. Quaas [2] O. Sourdeval [2] A. Gettelman [3]
[1]Imperial College London [2]Universitt Leipzig [3]National Center for Atmospheric Research
October 9, 2017

Aerosols and liquid clouds

- Aerosol modify the properties of liquid clouds

The albedo of a liquid cloud scene is a function of:

- Cloud fraction (CF)
- Liquid water path (LWP)
- Droplet number concentration (N_d)



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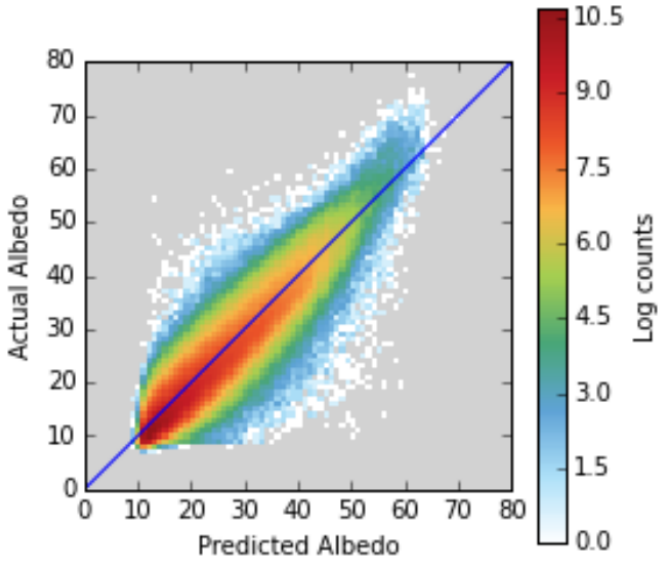

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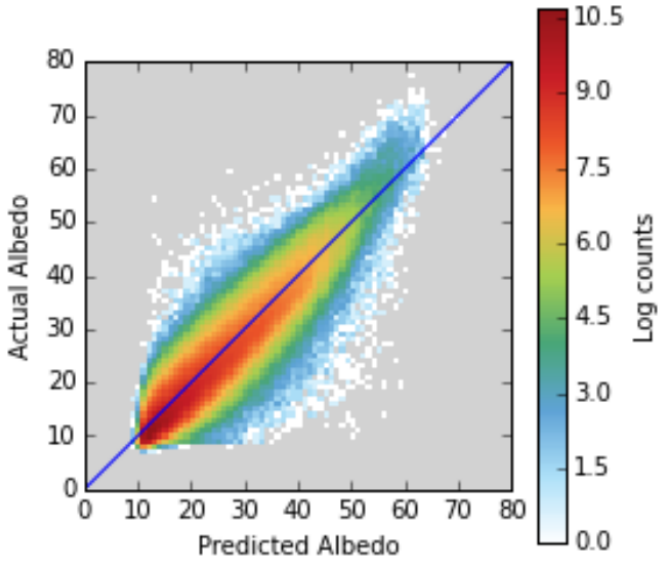

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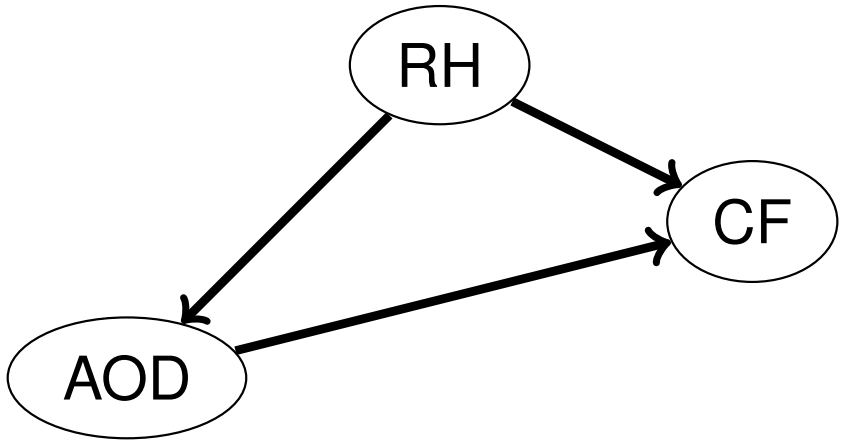

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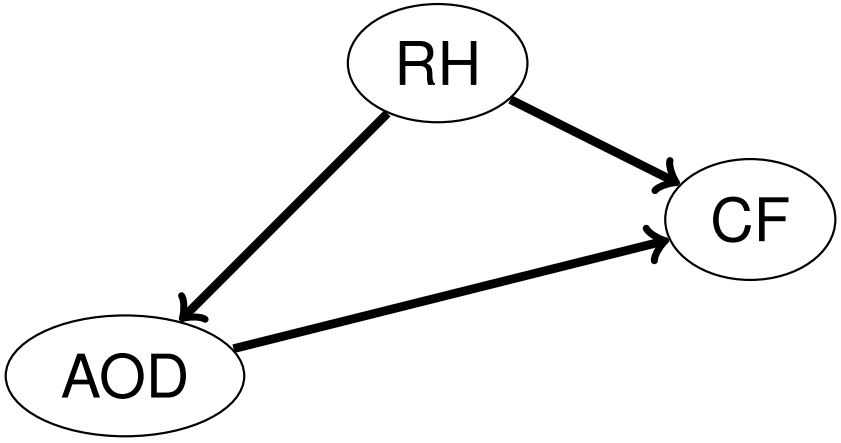

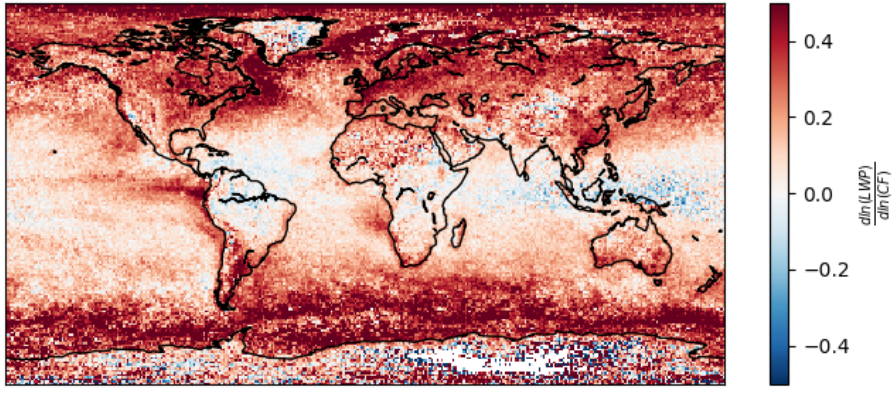

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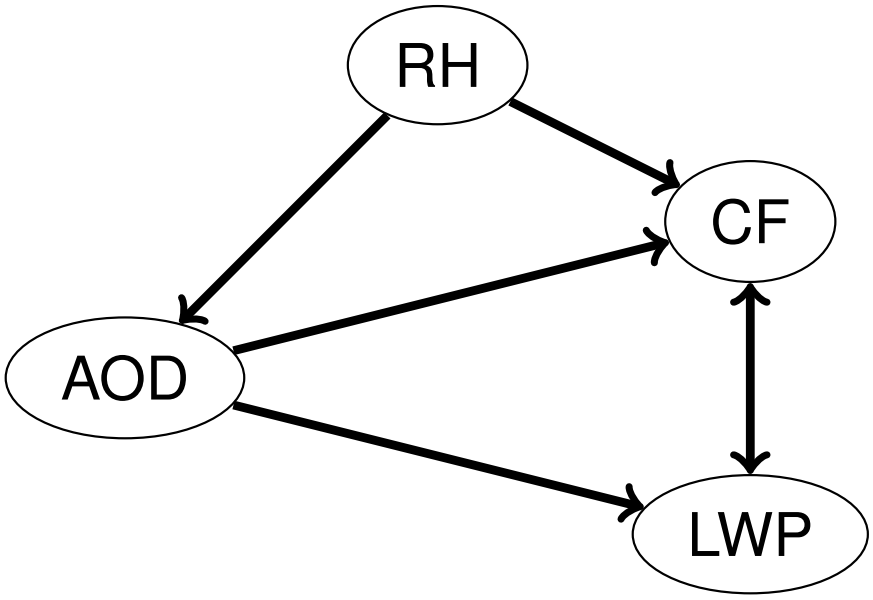

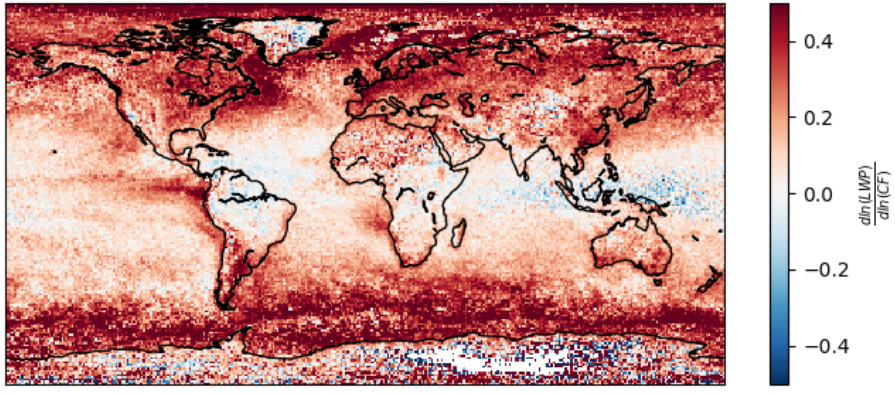

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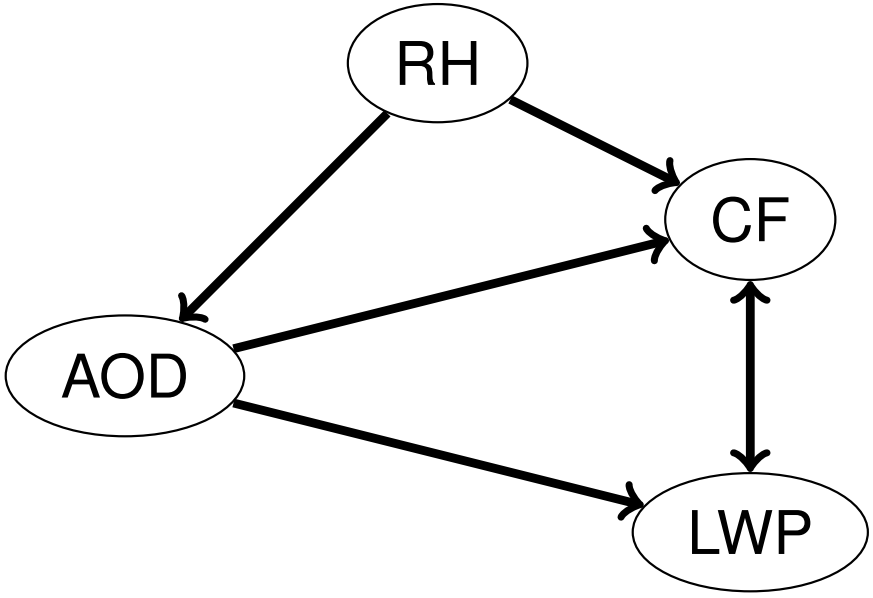
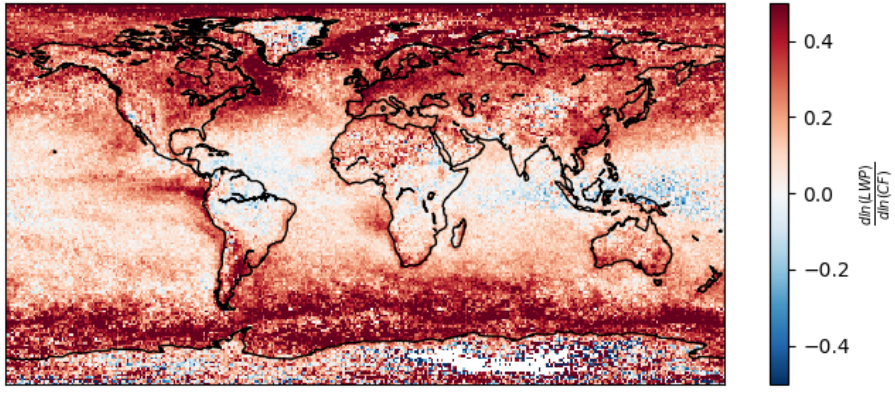
- How do we separate the aerosol effect?





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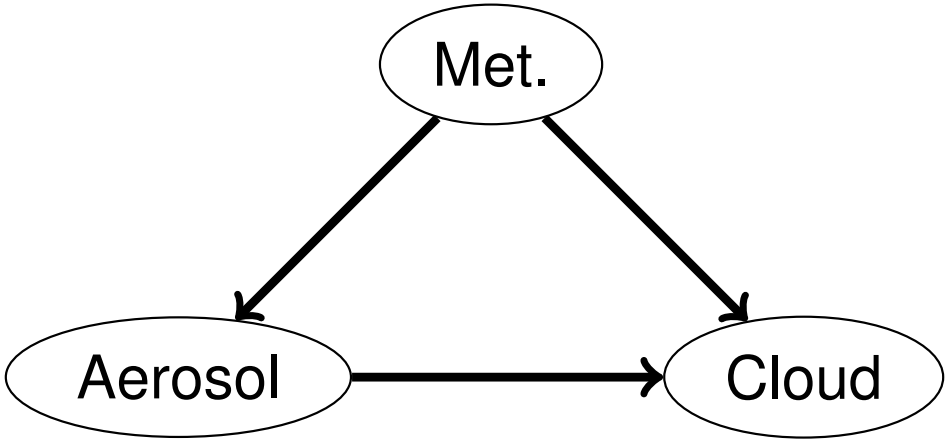
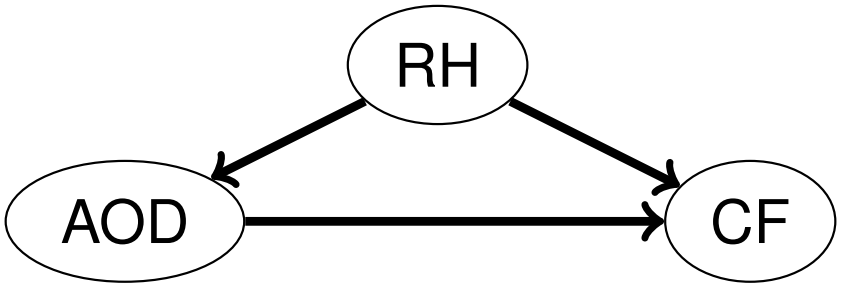


A number of different methods have been used:

- Controlling for confounders
- Exogenous perturbations (experiments)
- Mediating variables

Mediating variables



Gryspeerdt et al., JGR, 2016

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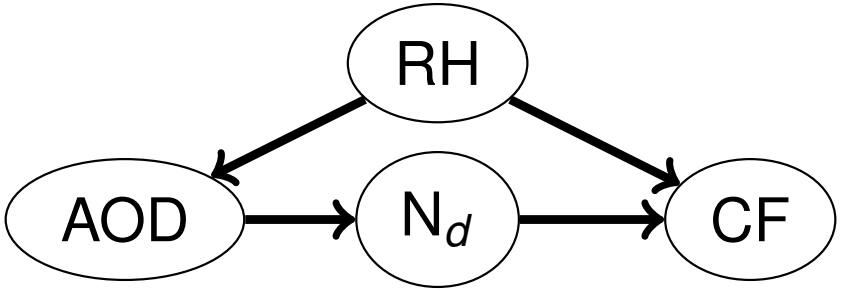

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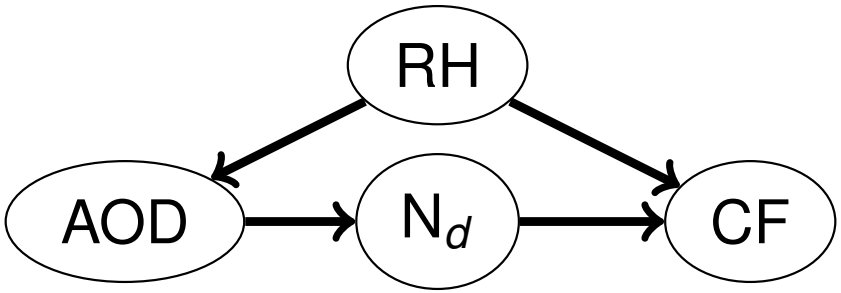

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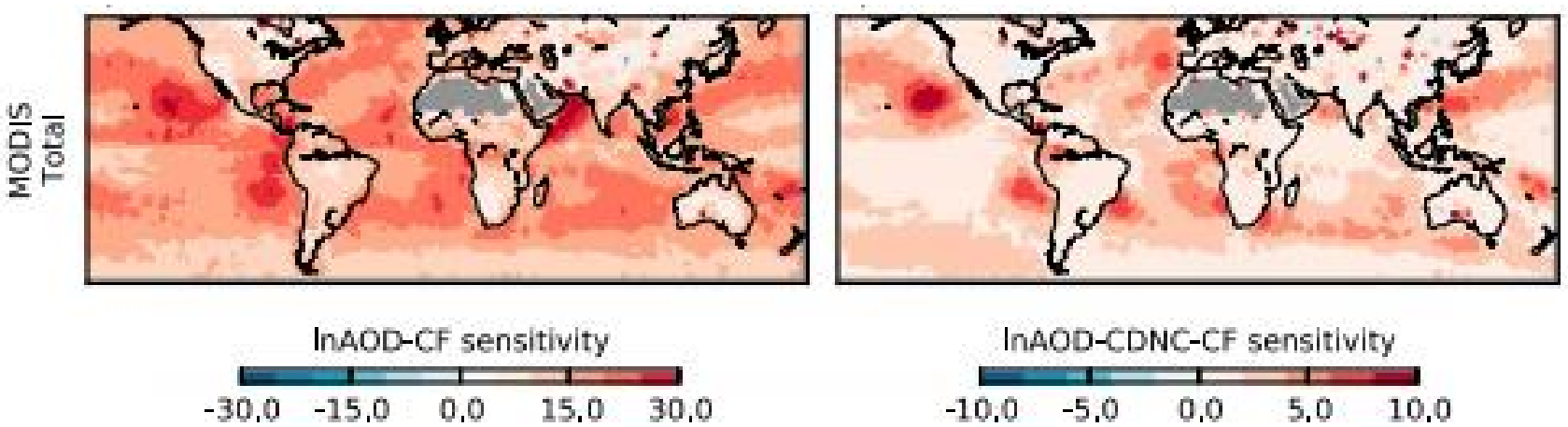

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Testing causality

Can we use this method for identifying the aerosol-LWP relationship?

$$\left.\frac{dLWP}{dAI}\right|_{causal} = \frac{dLWP}{dN_d} \times \frac{dN_d}{dAI}$$

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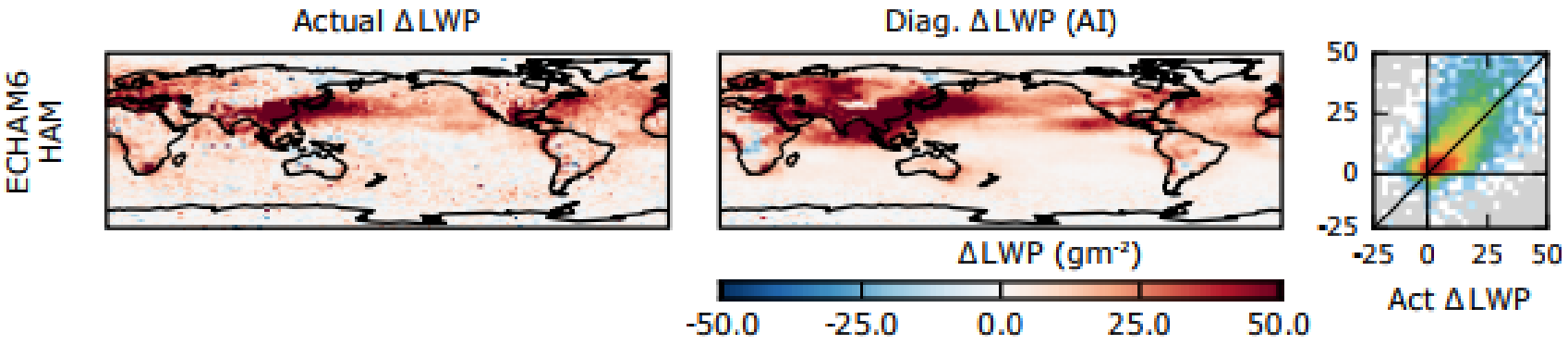
Note that we can't test this by setting N_d constant

$$\frac{dN_d}{dAI} = 0 \rightarrow \left.\frac{dLWP}{dAI}\right|_{causal} = 0$$

But it should also be able to "predict" the anthropogenic LWP change (ΔLWP_{actual})

Testing causality

$$\Delta LWP_{diag} = \left.\frac{dLWP}{dAI}\right|_{PD} \times \Delta AI$$



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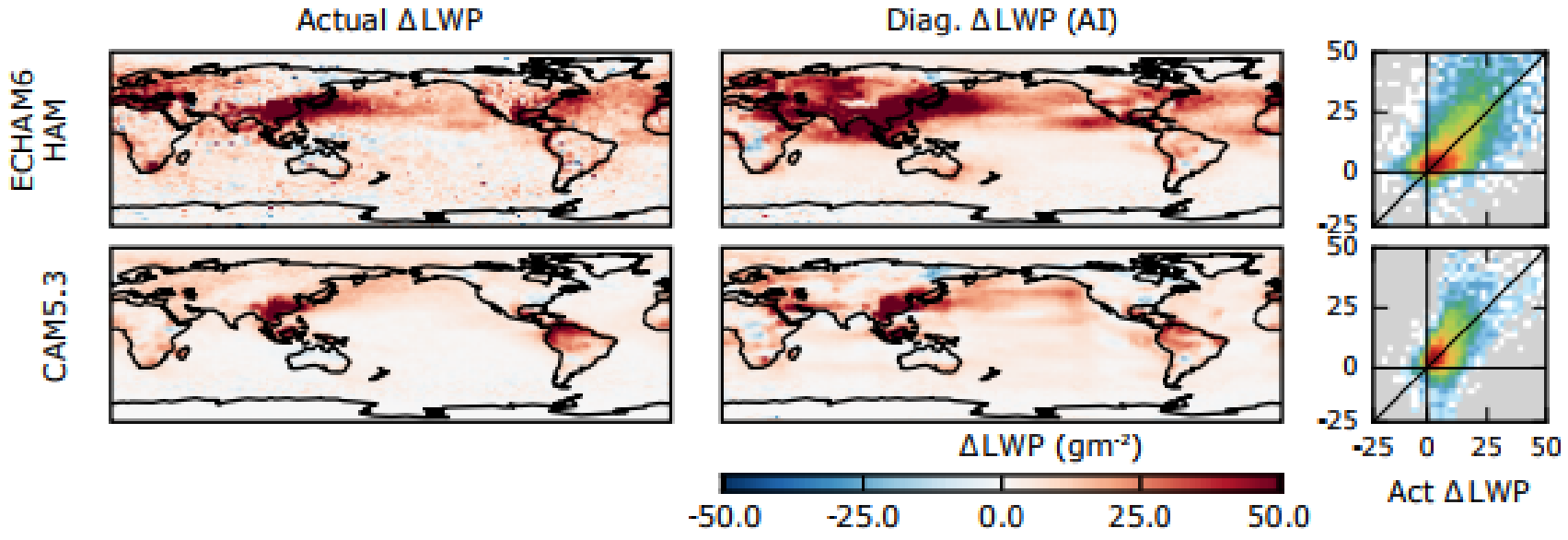

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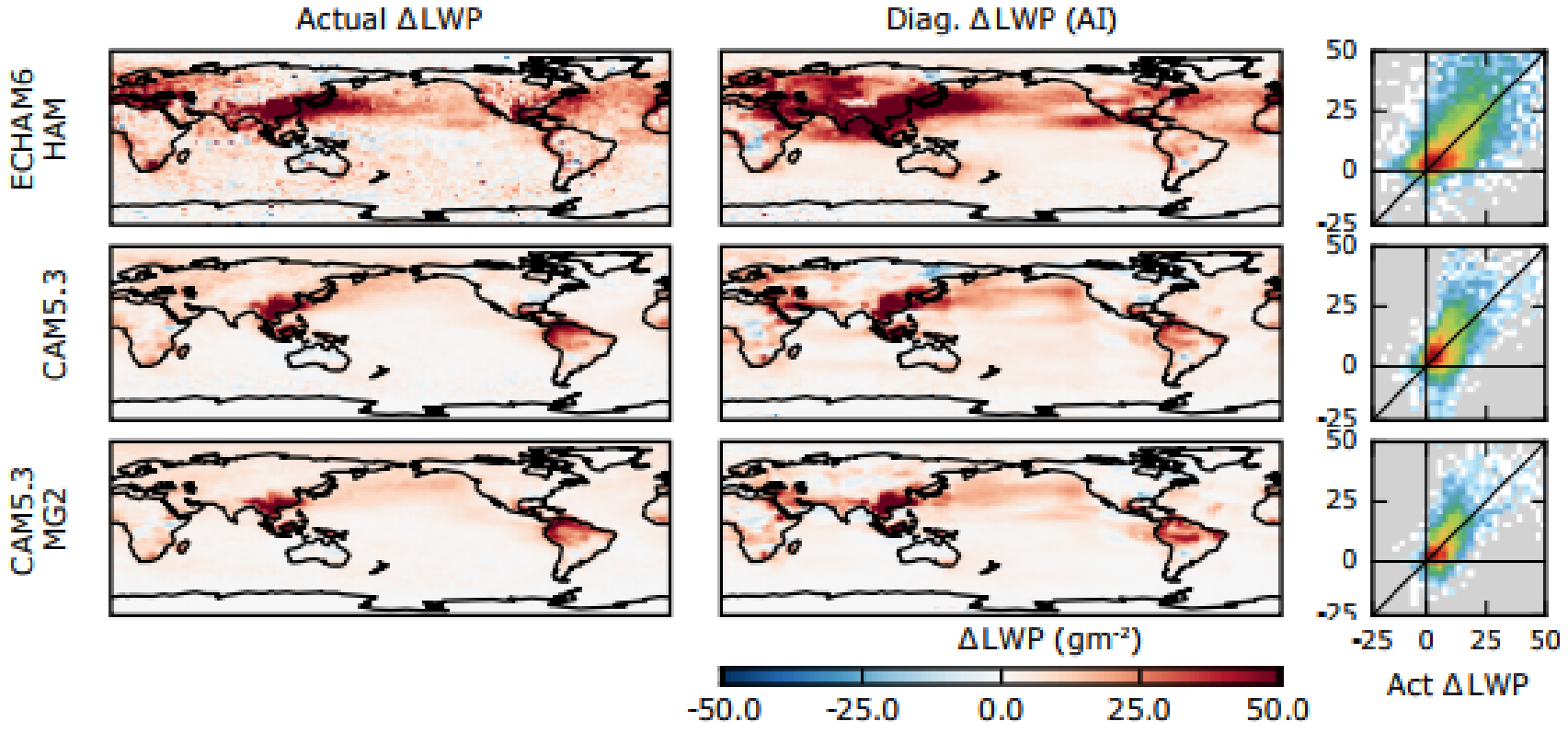

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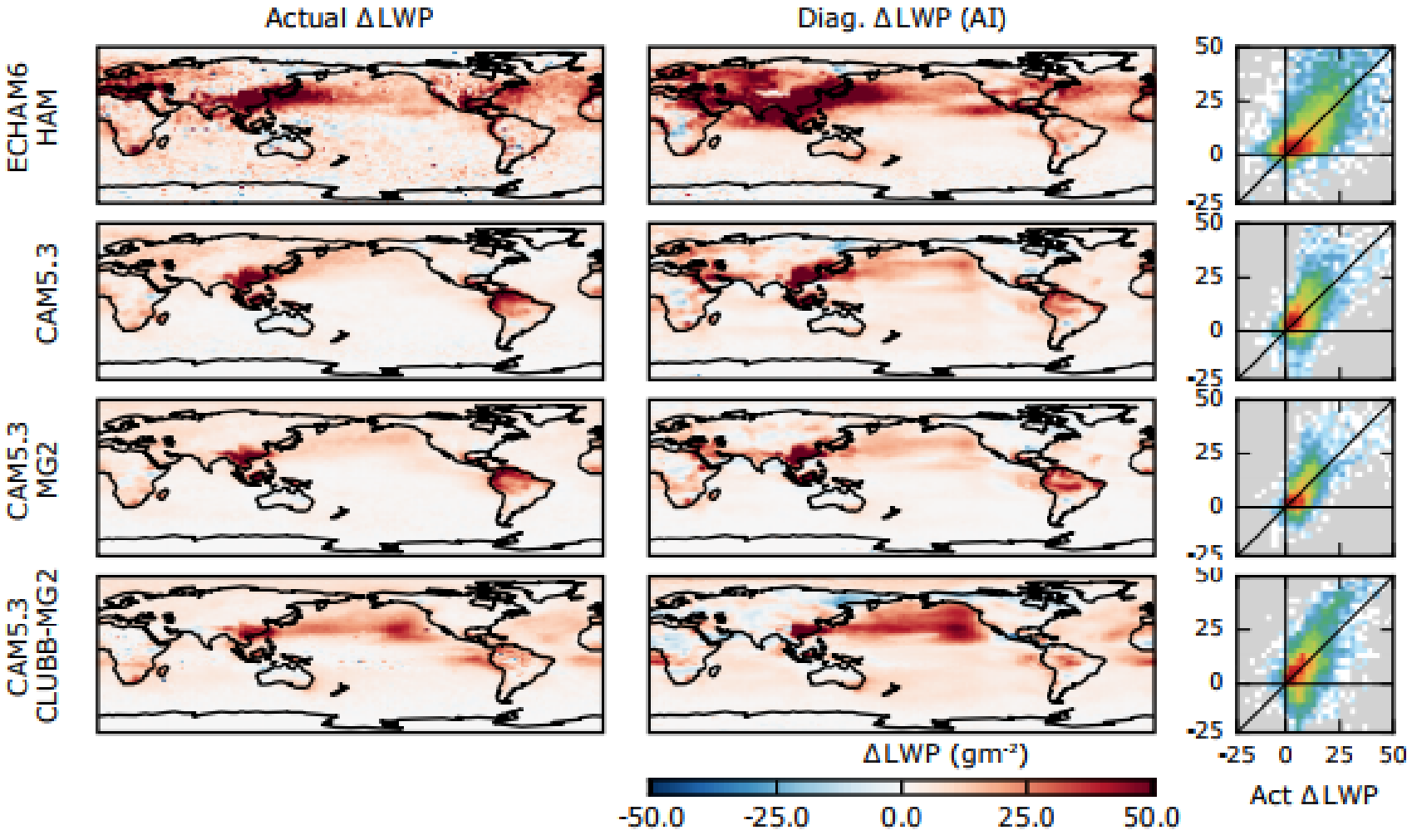
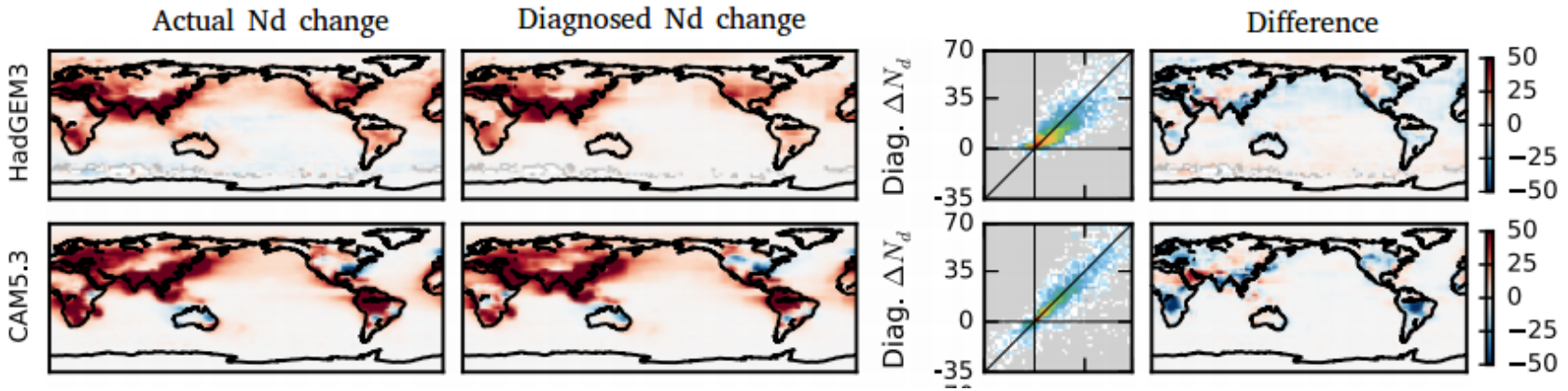
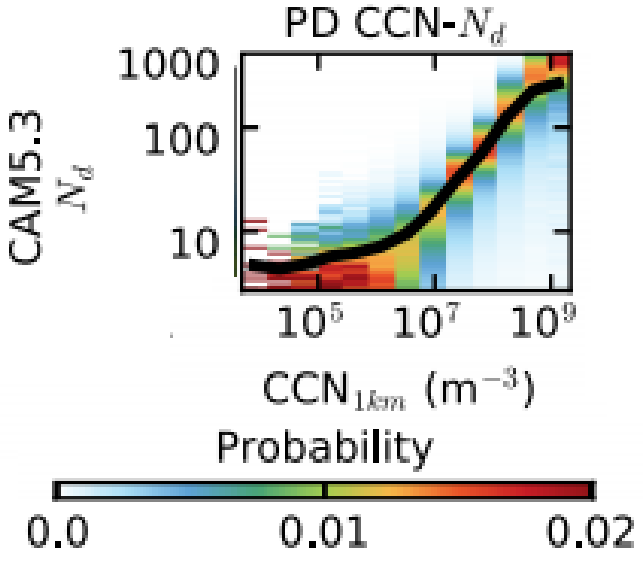


Calculating ΔN_d



- Anthropogenic ΔN_d can be accurately calculated from the present day CCN-N_d relationship

$$\Delta N_d = \left.\frac{dN_d}{dCCN}\right|_{PD} \times \Delta CCN$$



- Use conditional probabilities to conserve the non-linearity (e.g. $P(N_d|CCN)$)

Gryspeerdt et al, PNAS, 2017

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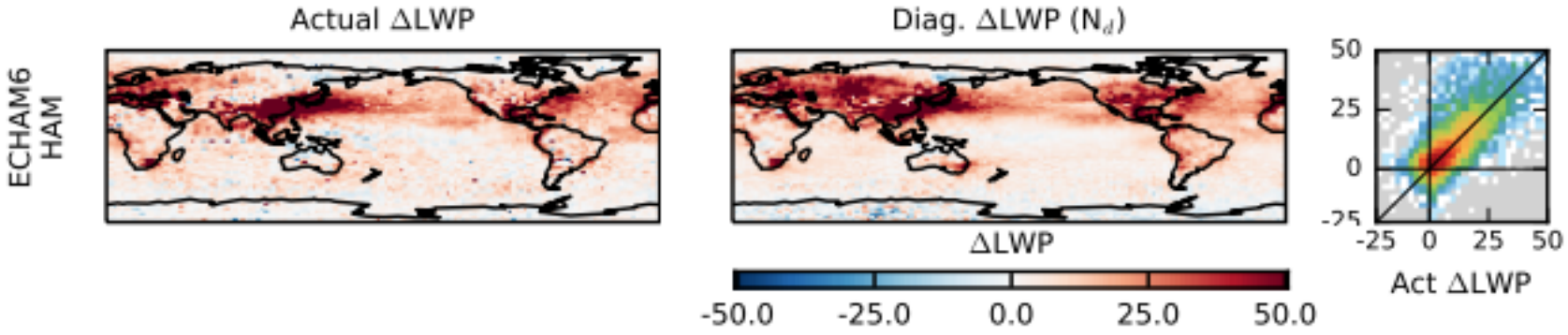
$$\Delta LWP_{diag} = \left.\frac{dLWP}{dN_d}\right|_{PD} \times \left(\left.\frac{dN_d}{dAI}\right|_{PD} \times \Delta AI \right) = \left.\frac{dLWP}{dN_d}\right|_{PD} \times \Delta N_d$$



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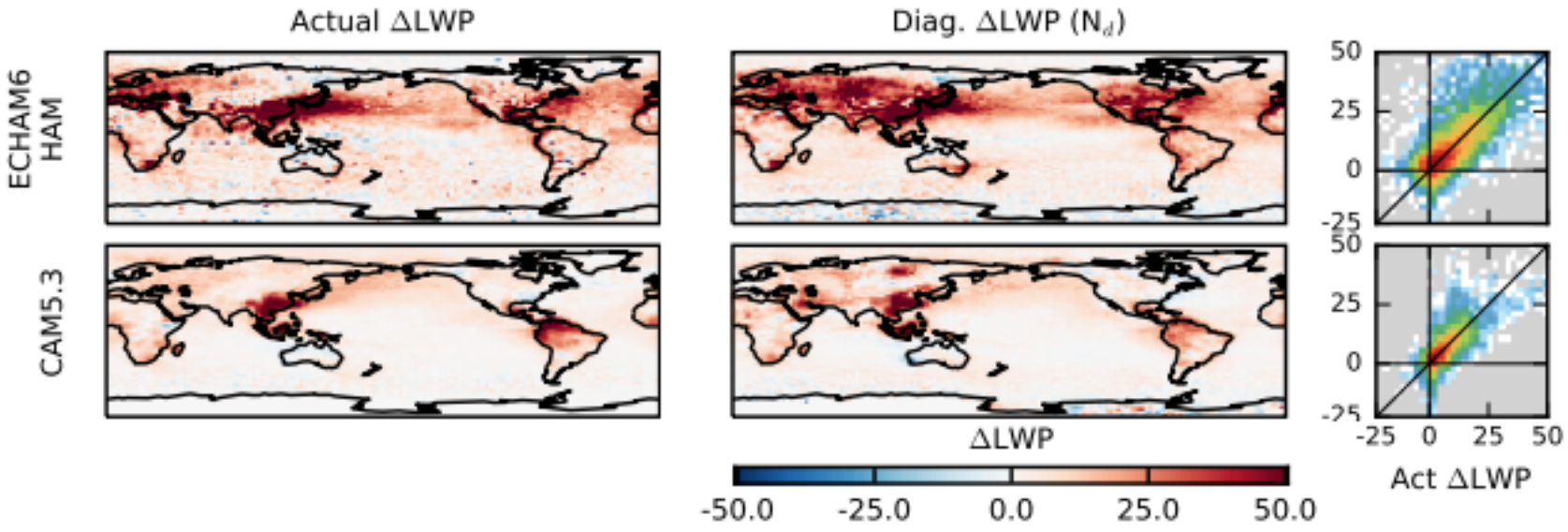

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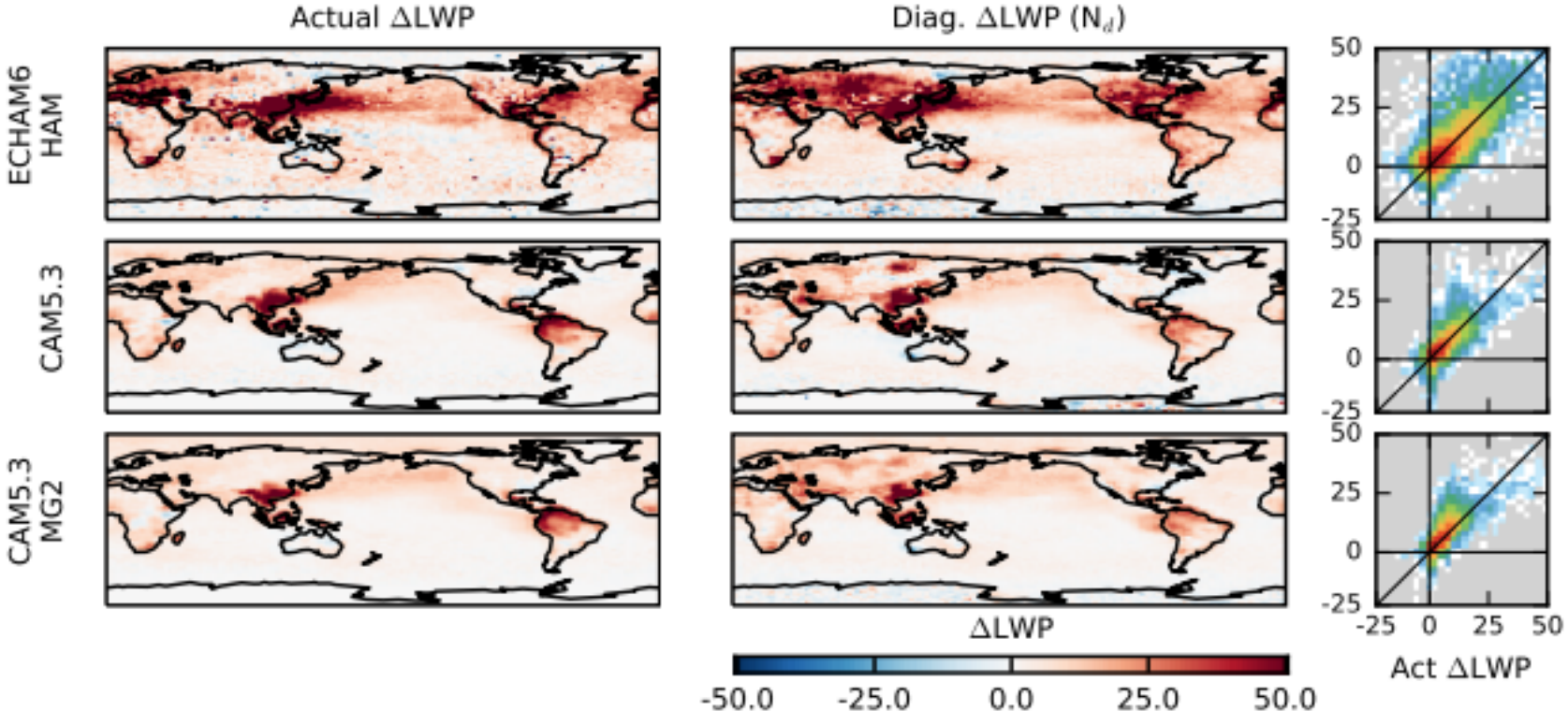

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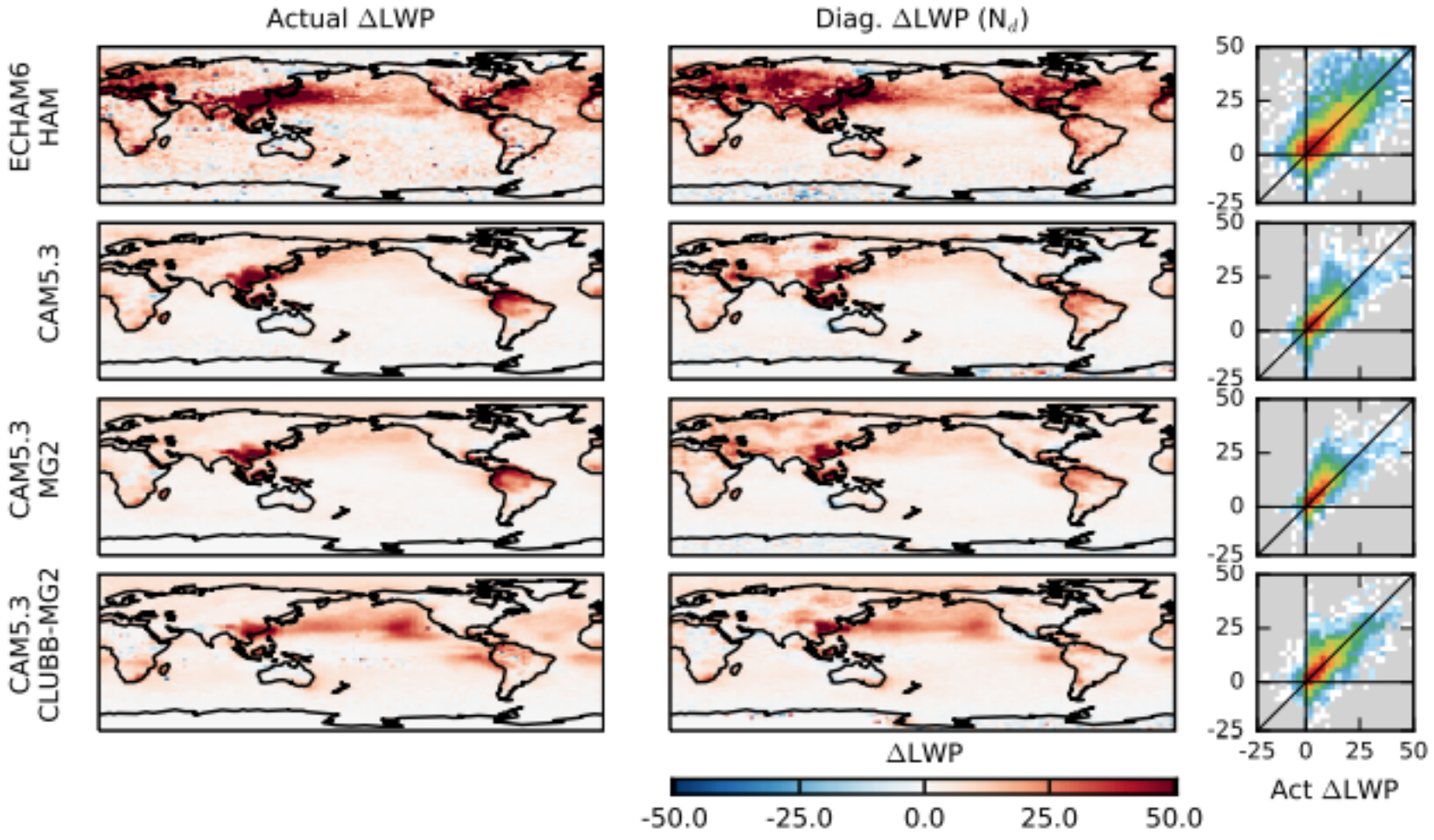

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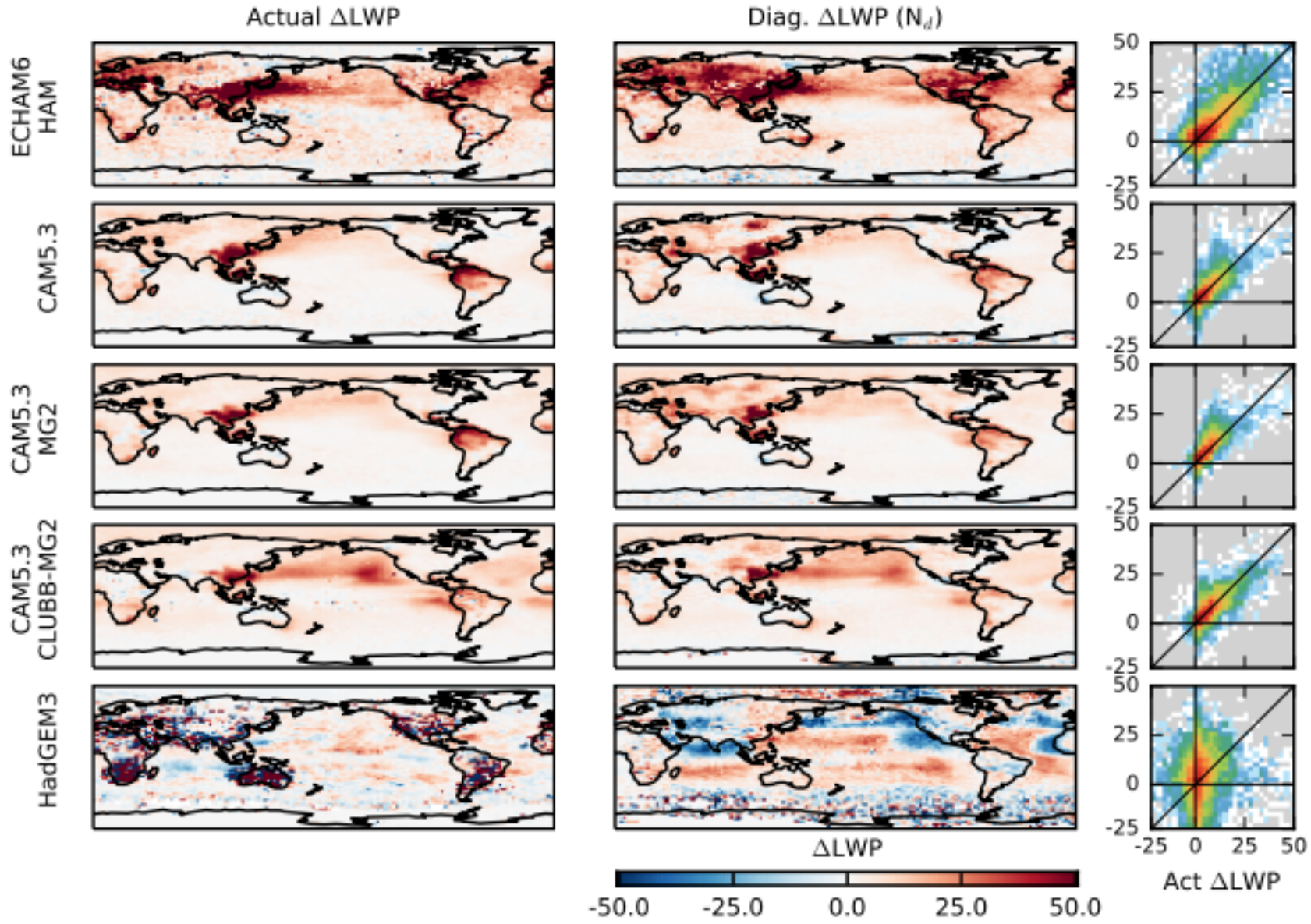
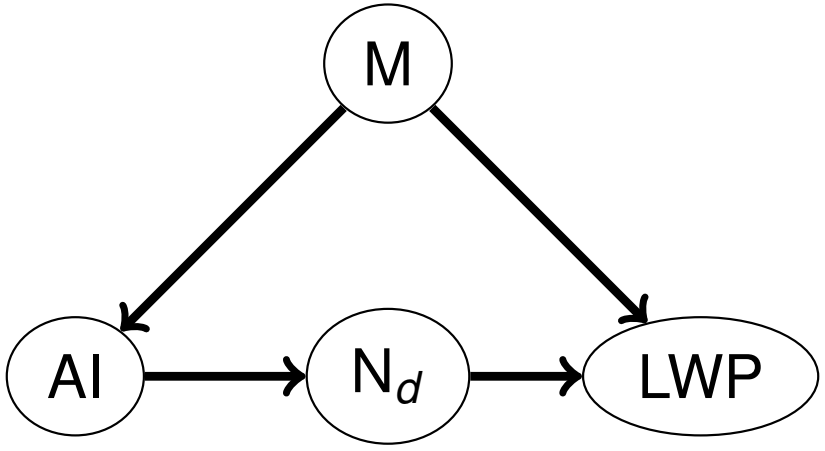


The CDNC-LWP relationship

Most of these models suggest a causal network of this form:



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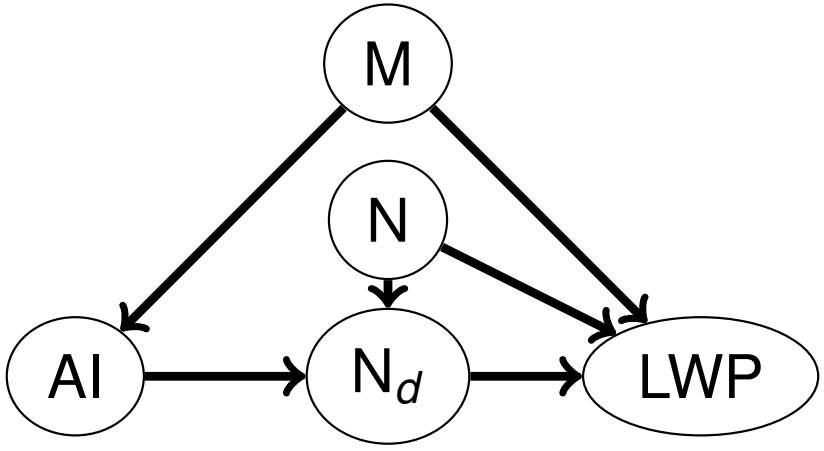

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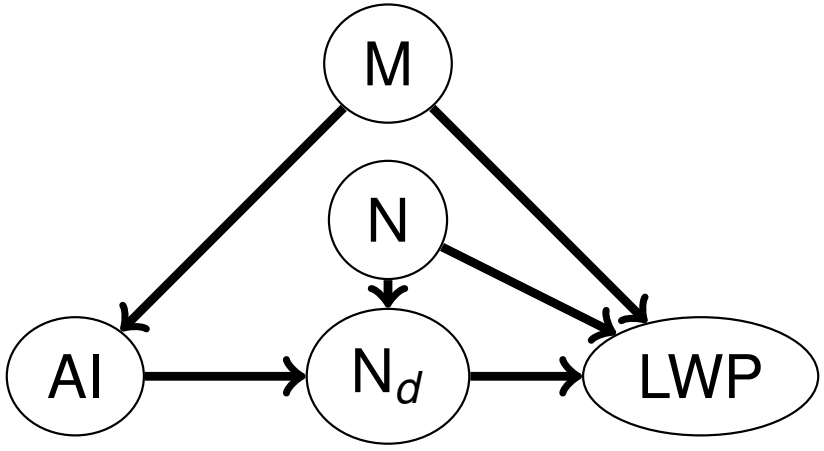

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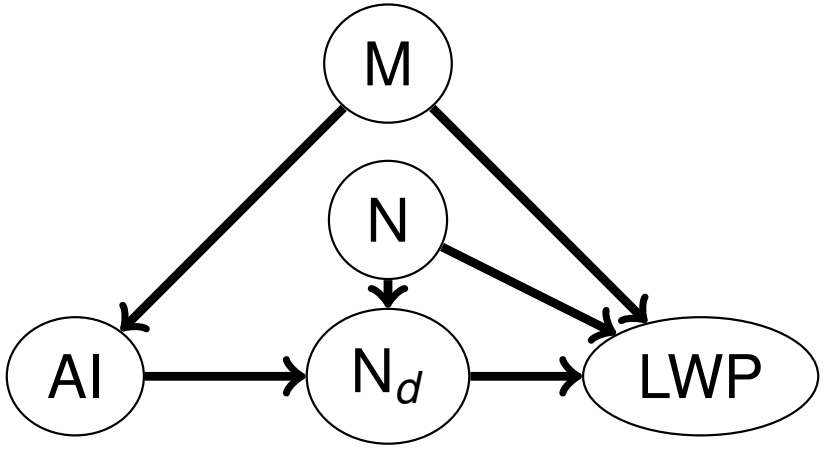

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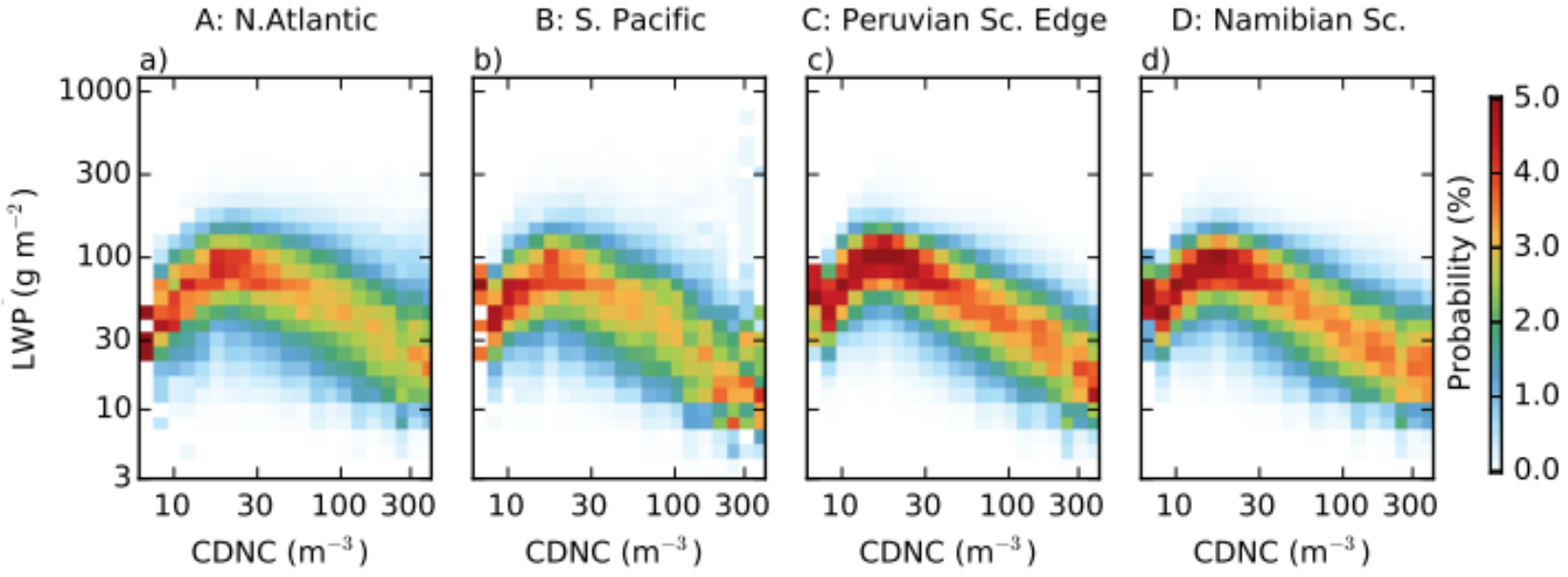
  - Systematic errors in cloud retrievals (e.g. sub-adiabaticity)
- Feedbacks
  - Aerosol dependent entrainment of dry air
  - (Aerosol processing)

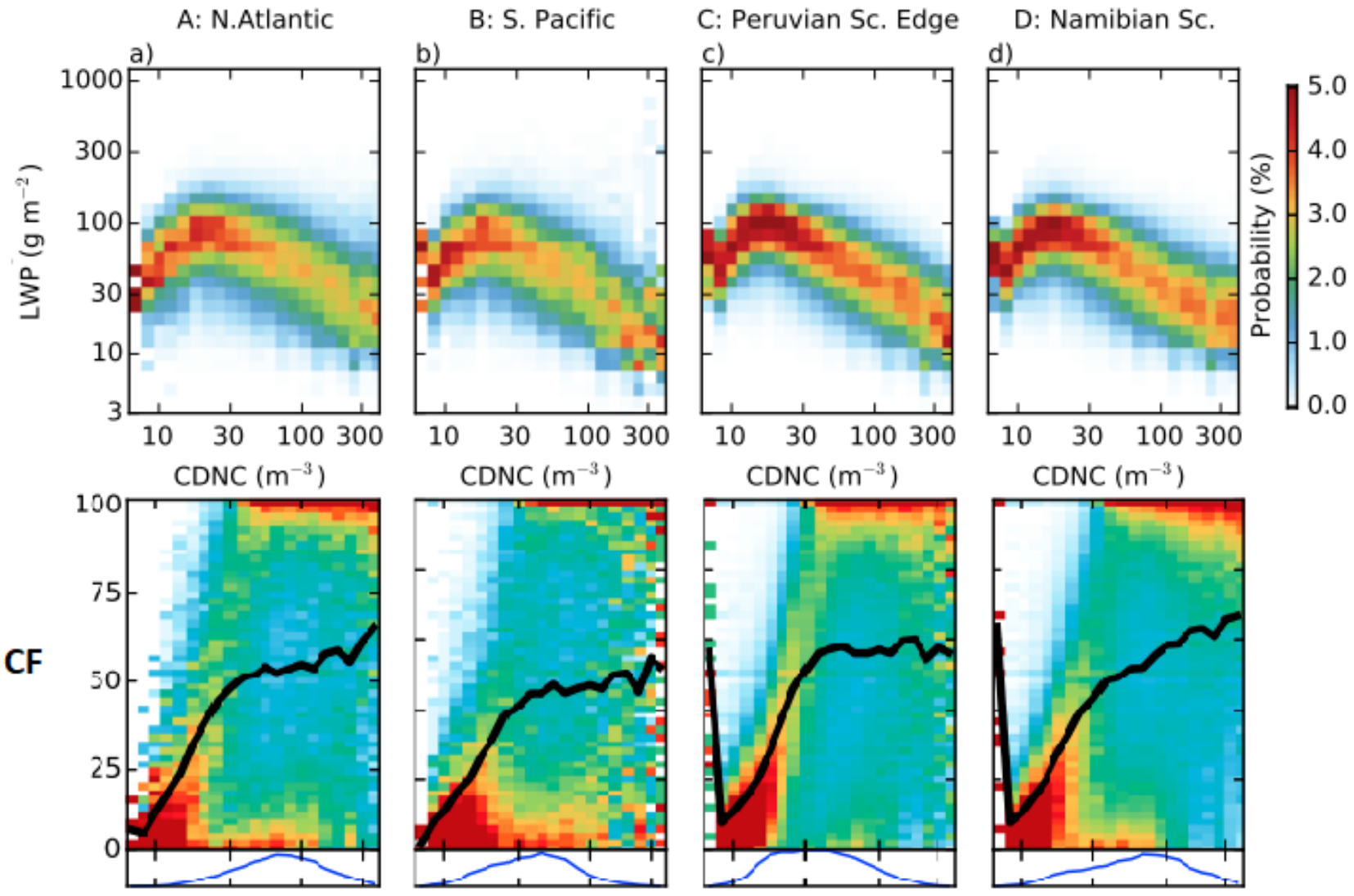
Satellite relationships



The N_d-LWP relationship in MODIS data is strongly non-linear

- Increase in LWP with increasing N_d at low N_d
- Decrease in LWP at high N_d

Satellite relationships



Correlated errors?

Both N_d ($\propto \tau_c^{0.5} r_e^{-2.5}$) and LWP ($\propto \tau_c r_e$) are calculated from r_e and τ_c

- Errors in r_e or τ_c generate correlated errors in N_d and LWP.

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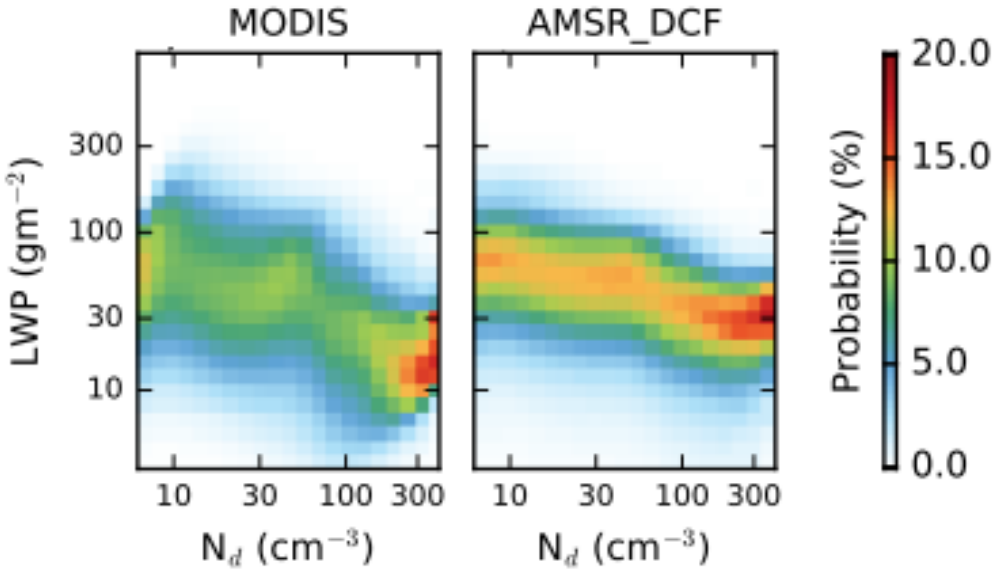

Similar results using MODIS and AMSR-E (microwave) LWP

- Retrieval errors don't dominate the relationship
- Although they still play a role

Implied forcing

What radiative forcing does this suggest?

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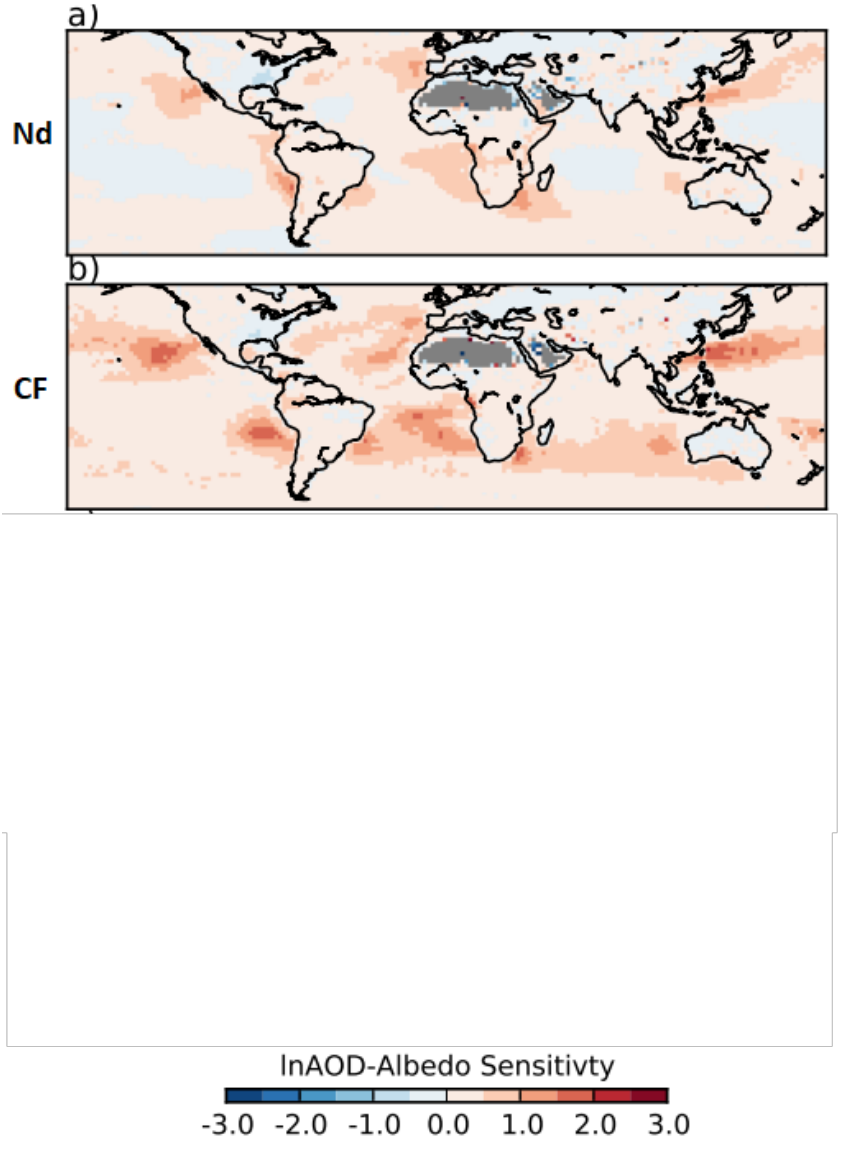

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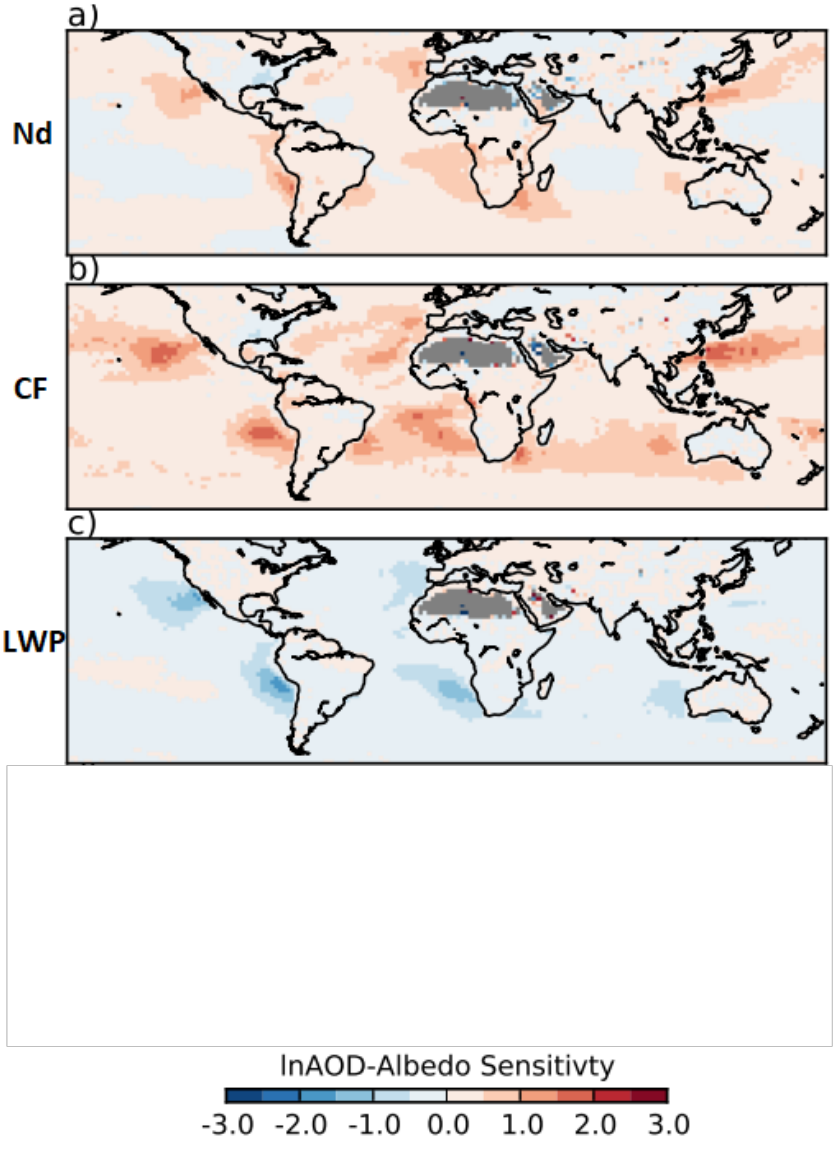

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- Changes in LWP (mediated by N_d)
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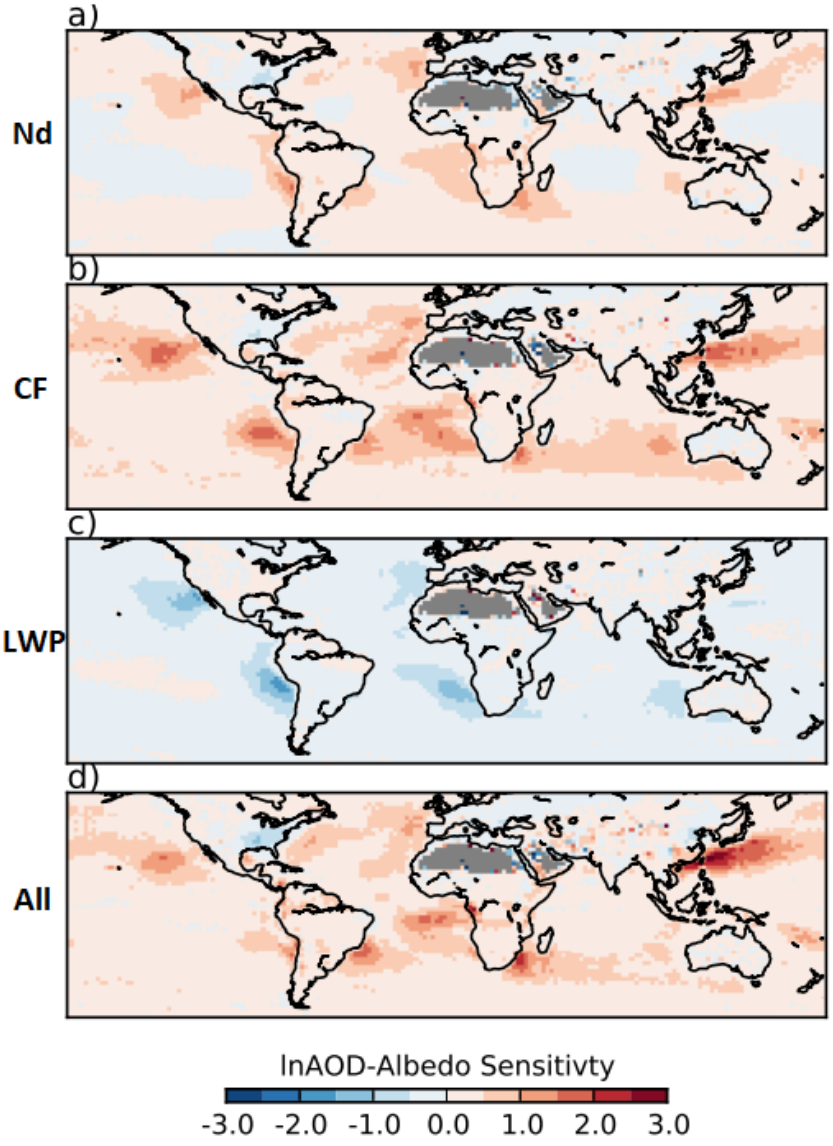
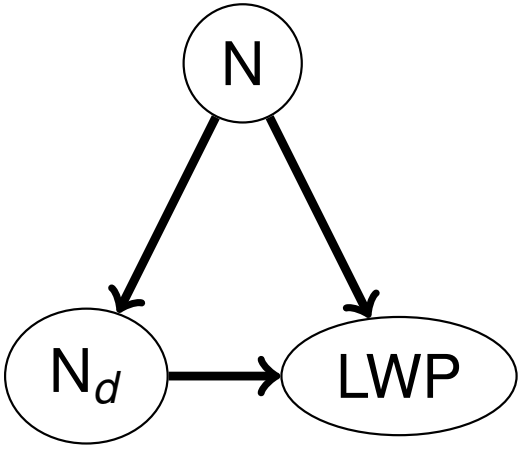
- Total (liquid clouds only)
  - $\approx$-0.51 Wm^{-2}



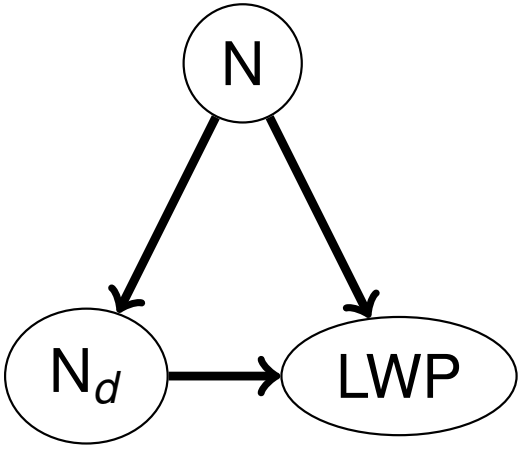
Summary

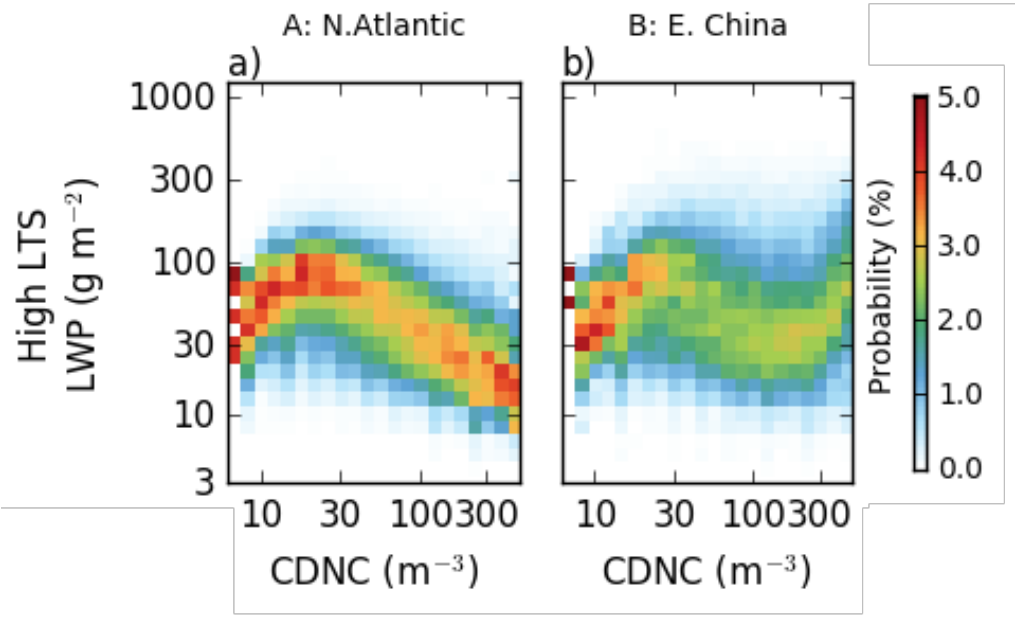
Exogenous perturbations



If the N_d-LWP relationship is causal, it should hold under all conditions

Exogenous perturbations





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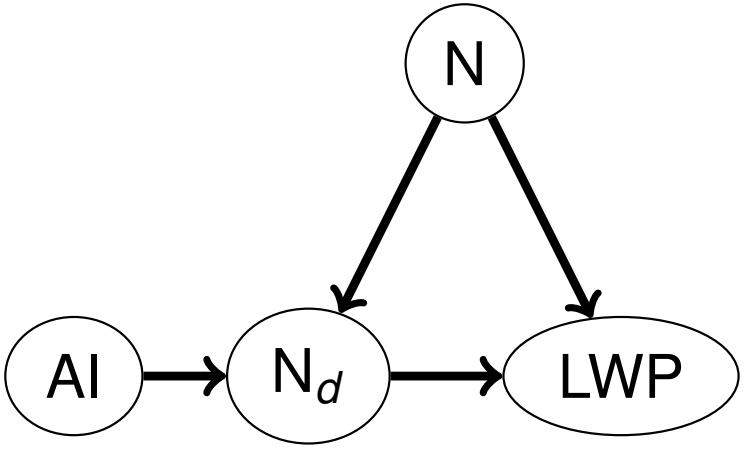

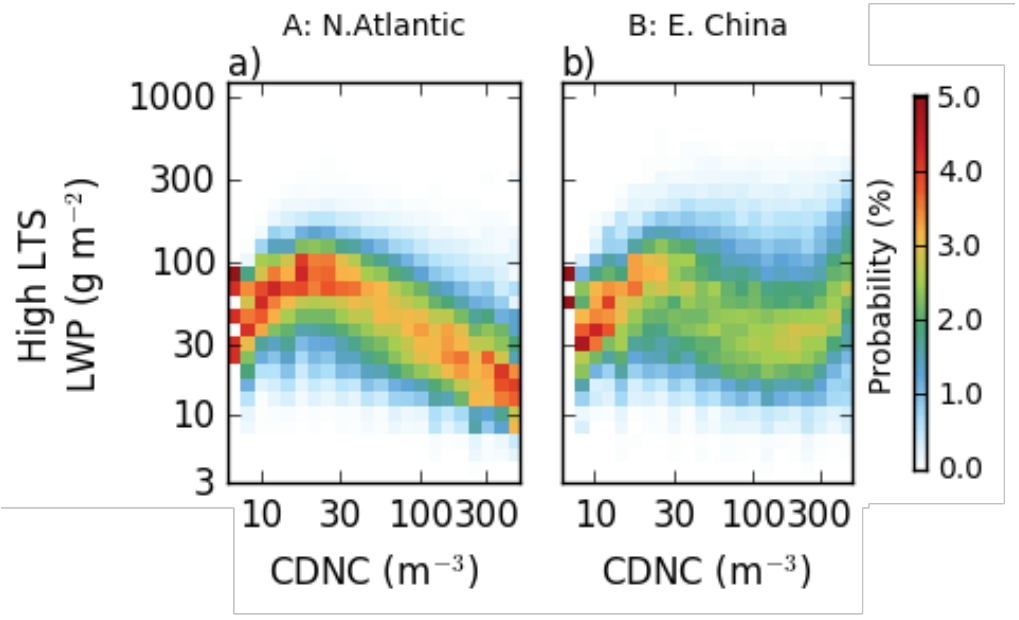

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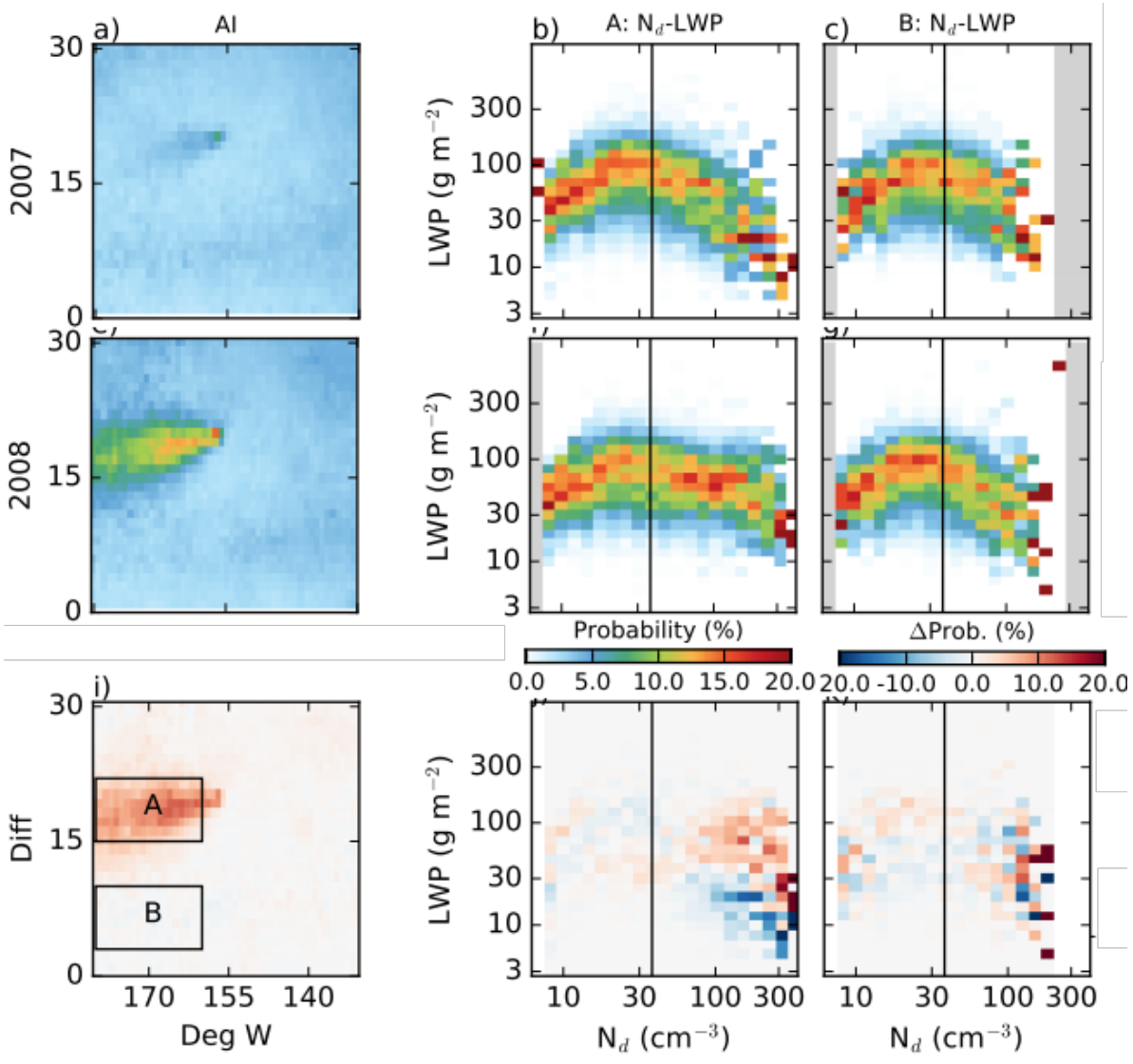
Conditions where the N_d is varied exogenously provide an opportunity to test this

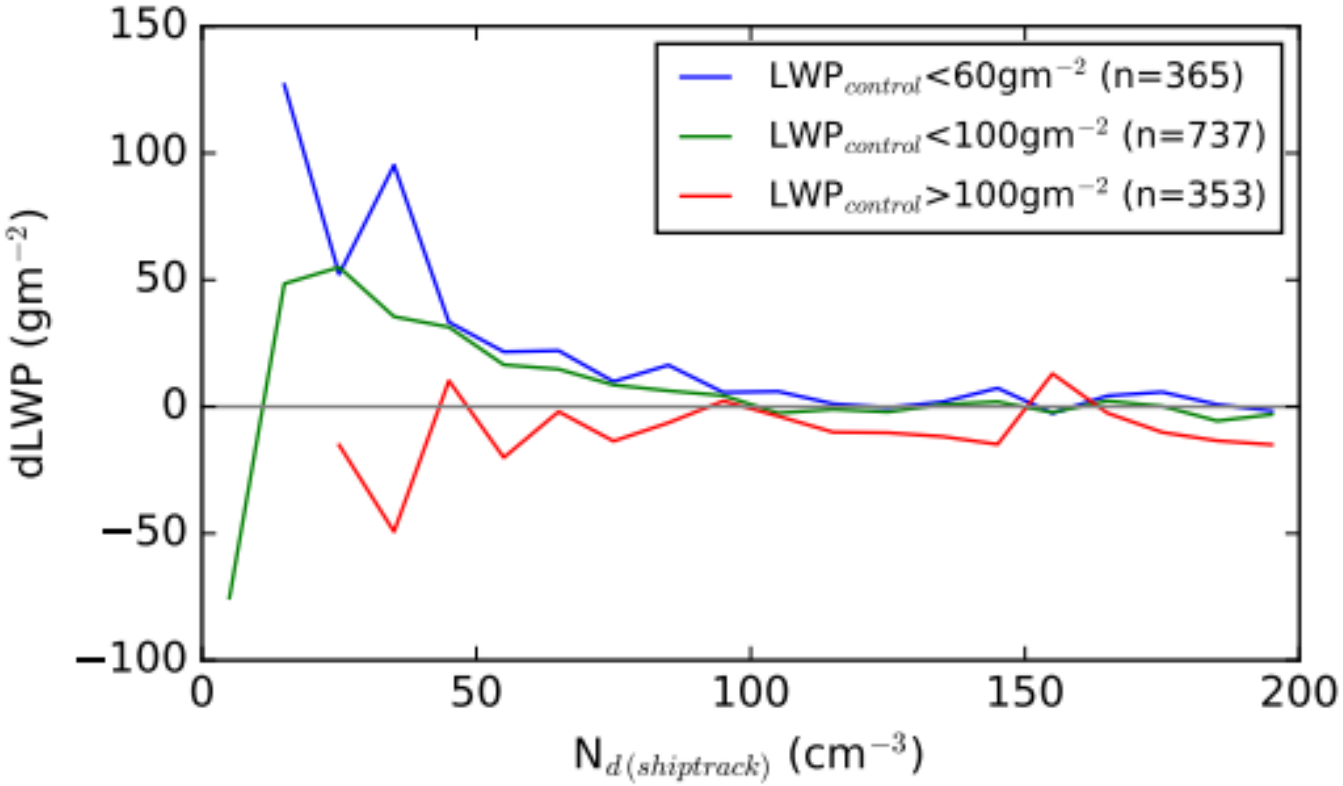
- Volcanoes
- Shiptracks

Volcanic emissions



- In 2007, N_d-LWP similar in regions A and B
- Region A shows weaker LWP decrease with N_d in 2008
- Suggests little LWP change at high N_d

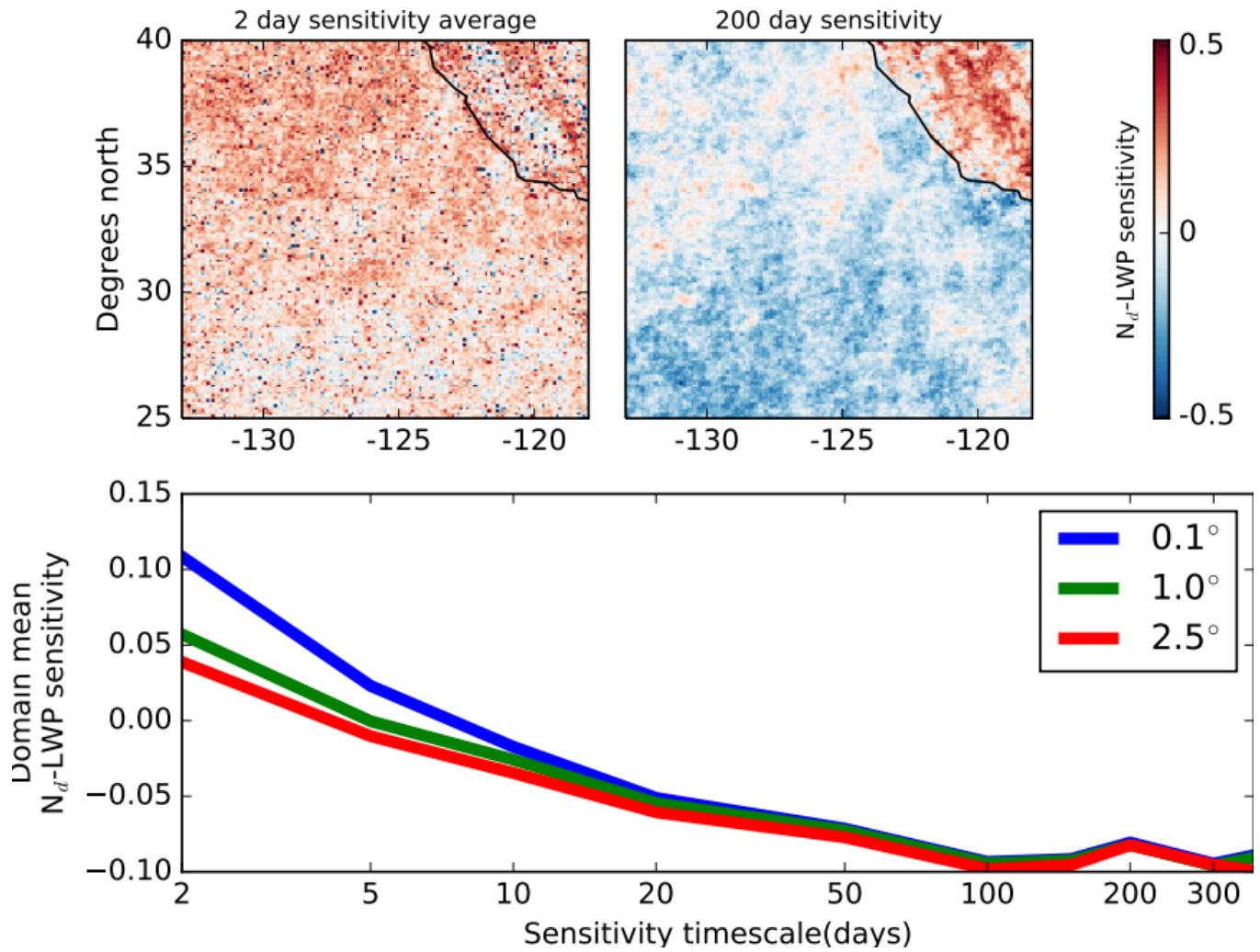
Shiptracks



- A similar effect is observed in shiptracks
- LWP increases in shiptracks where the “shiptrack” N_d is low
- No change in LWP at high “shiptrack” N_d

Thanks to Matt Christensen for shiptrack data!

Scale dependence



- The N_d-LWP relationship is scale dependent
- Must reach temporal/spatial scale where N_d is varied by aerosol

Summary

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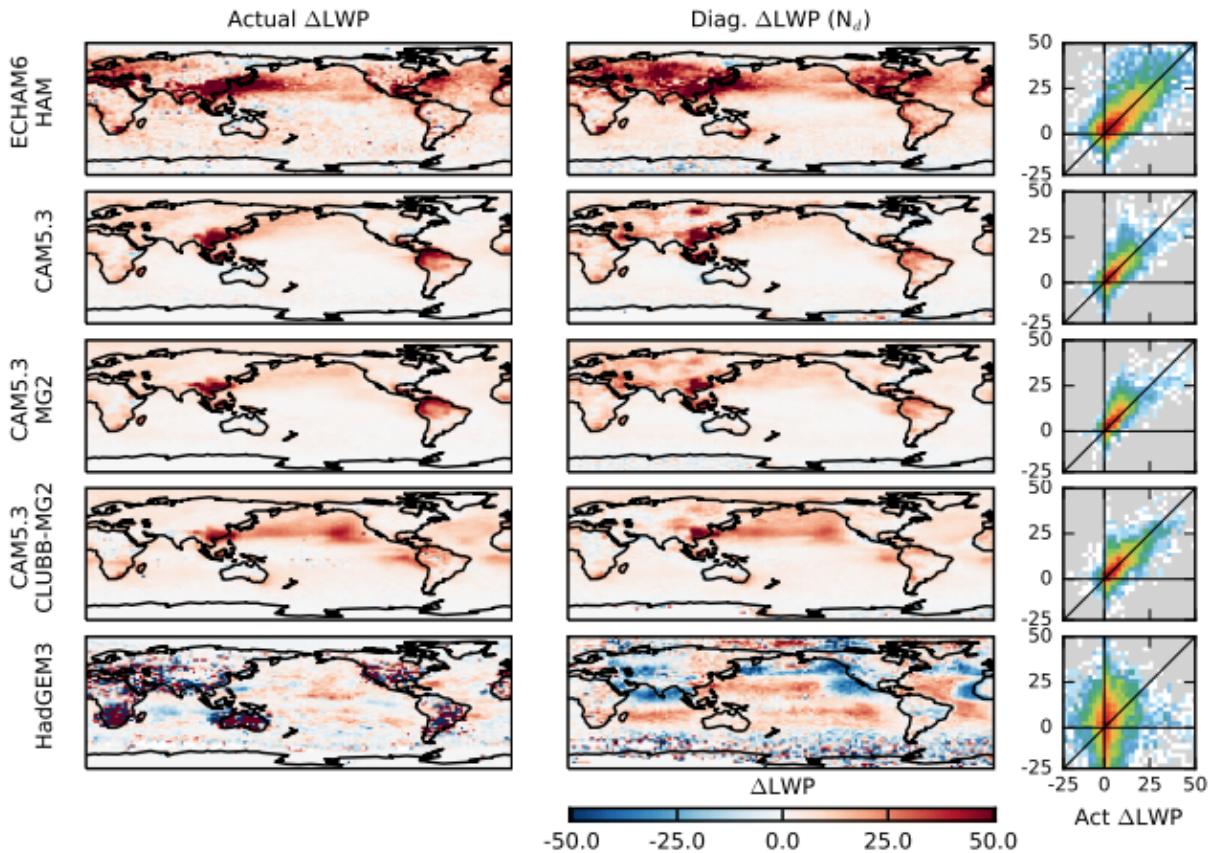
  - The (plain) AI-LWP relationship overestimates the role of aerosols
  - The N_d-LWP seems a good choice (with caveats!)



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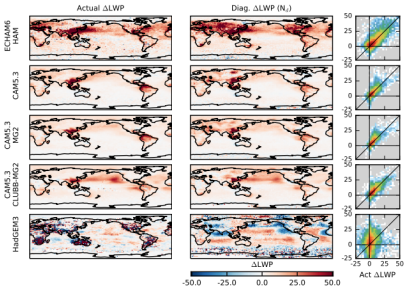

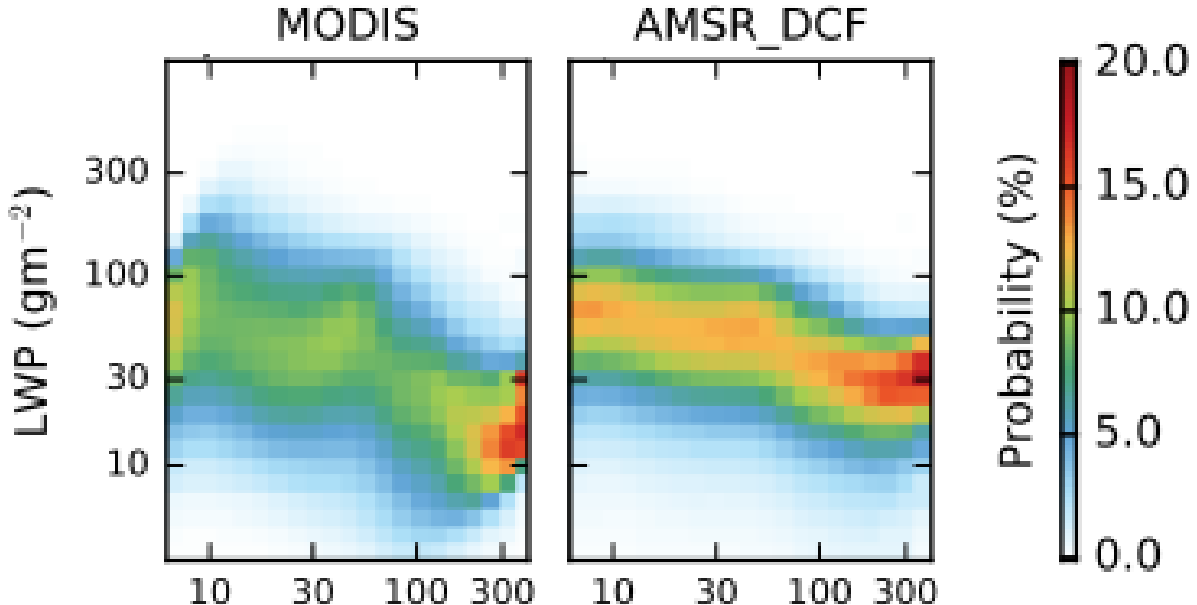

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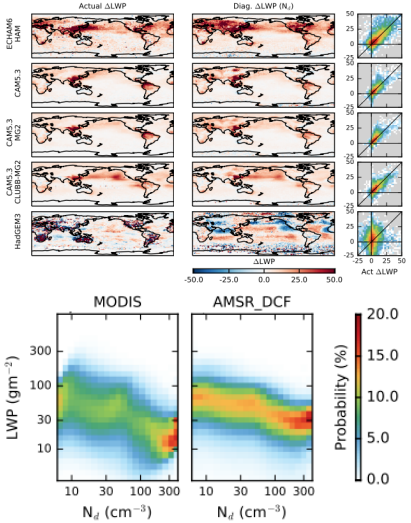

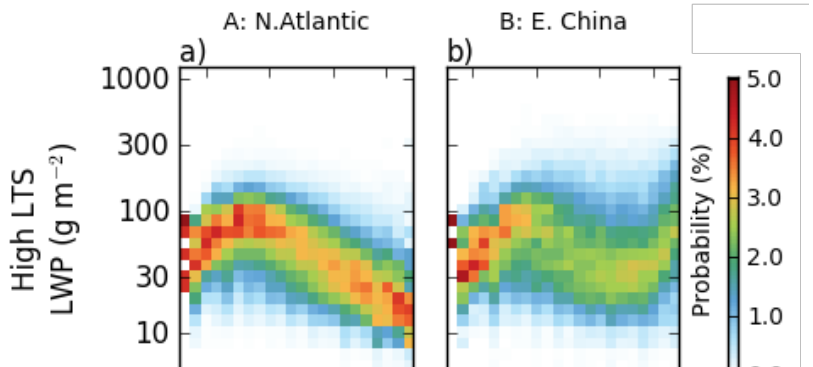

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- What about ice processes... ?