Untangling causality in aerosol-cloud adjustments

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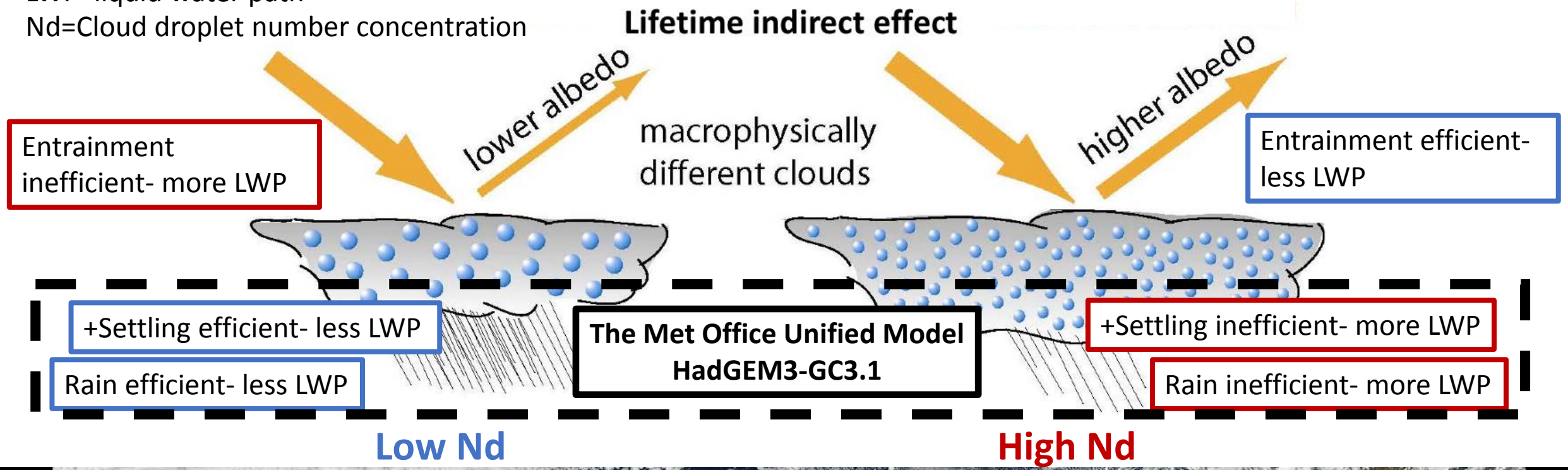
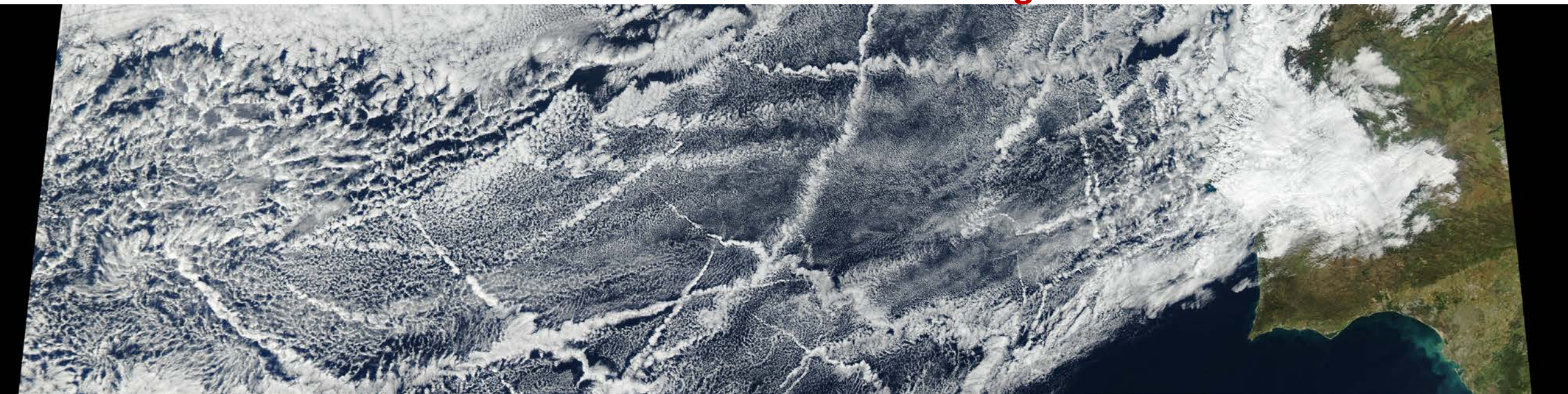
LWP=liquid water path
Nd=Cloud droplet number concentration



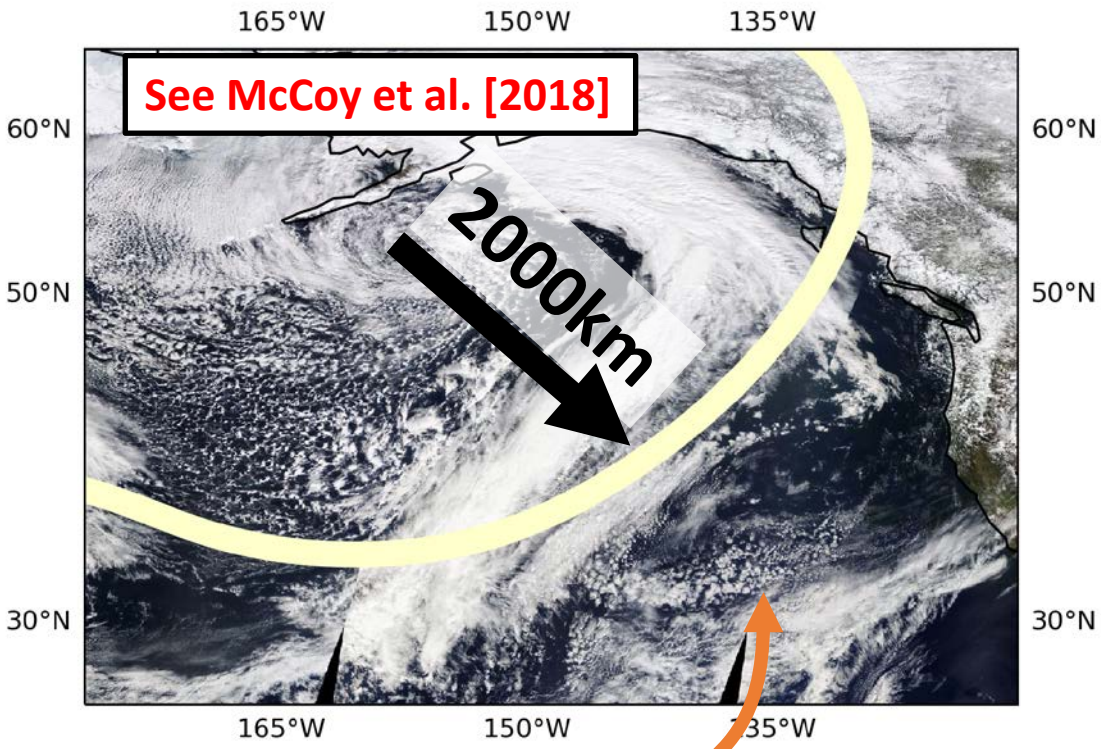


So do clouds have higher LWP when Nd is high?

Hard to say- most variability in clouds is driven by weather!

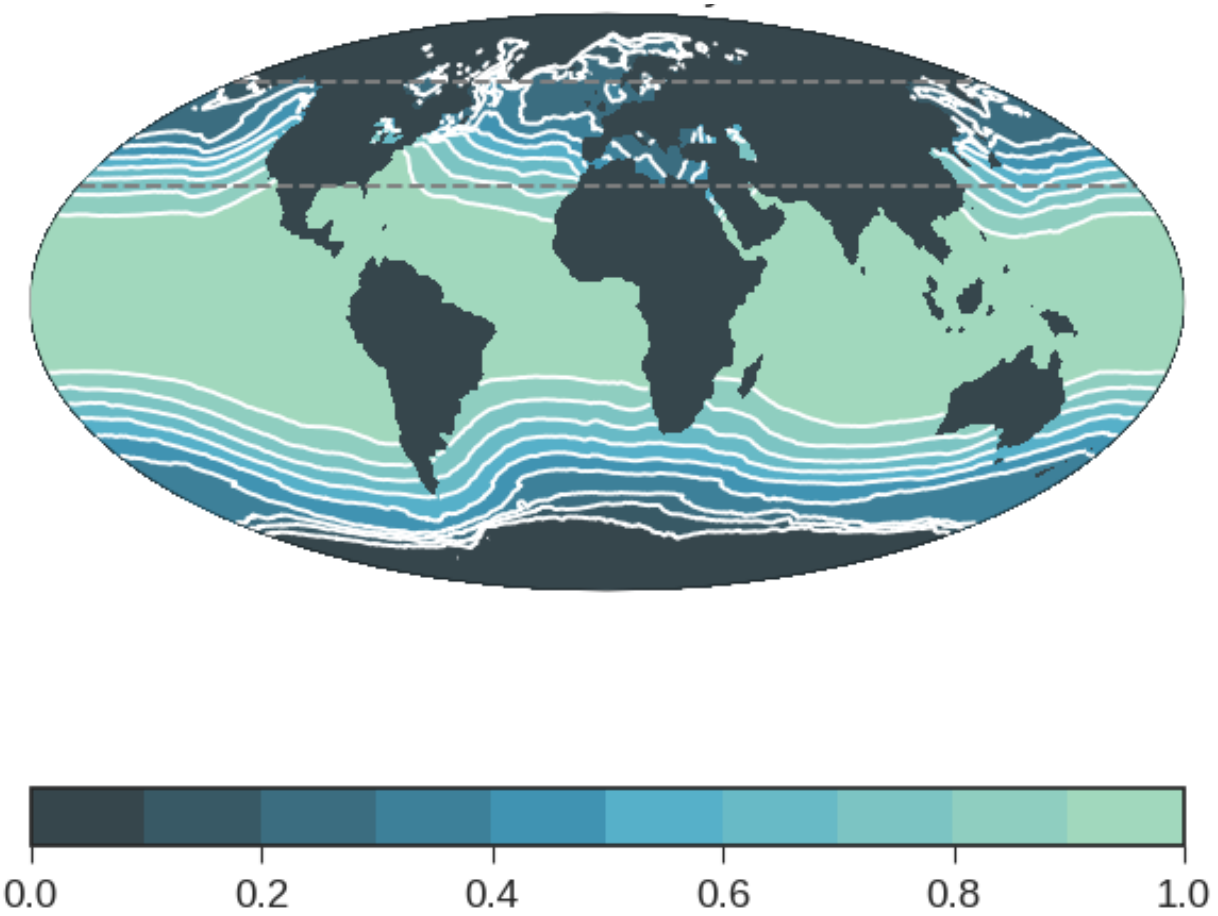
Synoptic states

Use Field and Wood 2007 SLP-based cyclone compositing



We want to look at this now

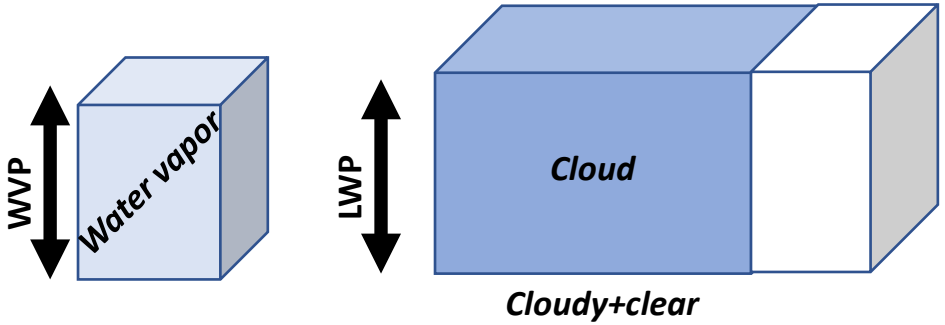
Fraction of time 2000km from cyclone center



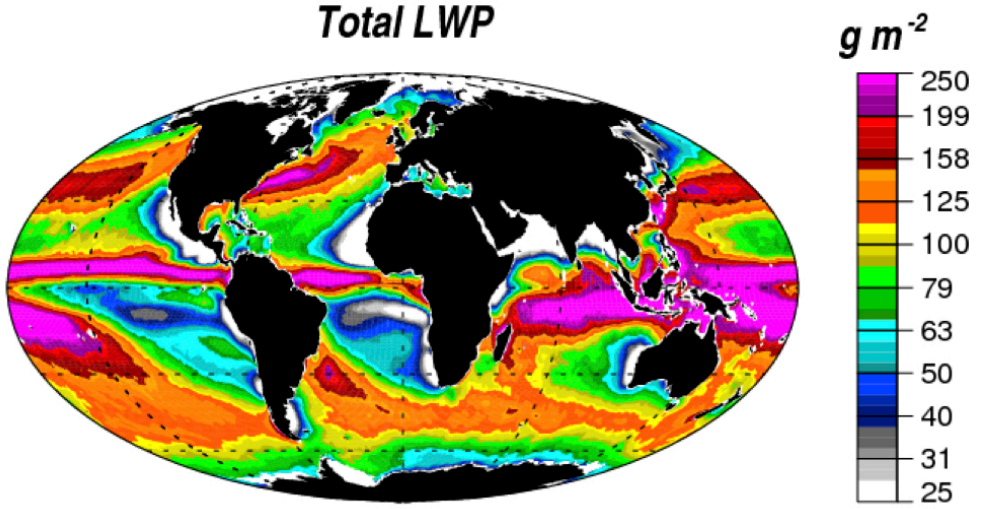
Observational data

- **MODIS:** Cloud droplet number concentration (Nd)
- **MAC-LWP: Multisensor Analysis Climatology** wind speed, water vapor path (WVP), liquid water path (LWP)
- Pros:
  - Retrieval doesn't share information with Nd from MODIS.
  - Comparison to models is easy.
  - Not sensitive to overlap.
- Cons:
  - Difficult to differentiate changes in extent from thickness. Hard to compare to previous studies.
  - Only available over oceans.

For microwave observations:

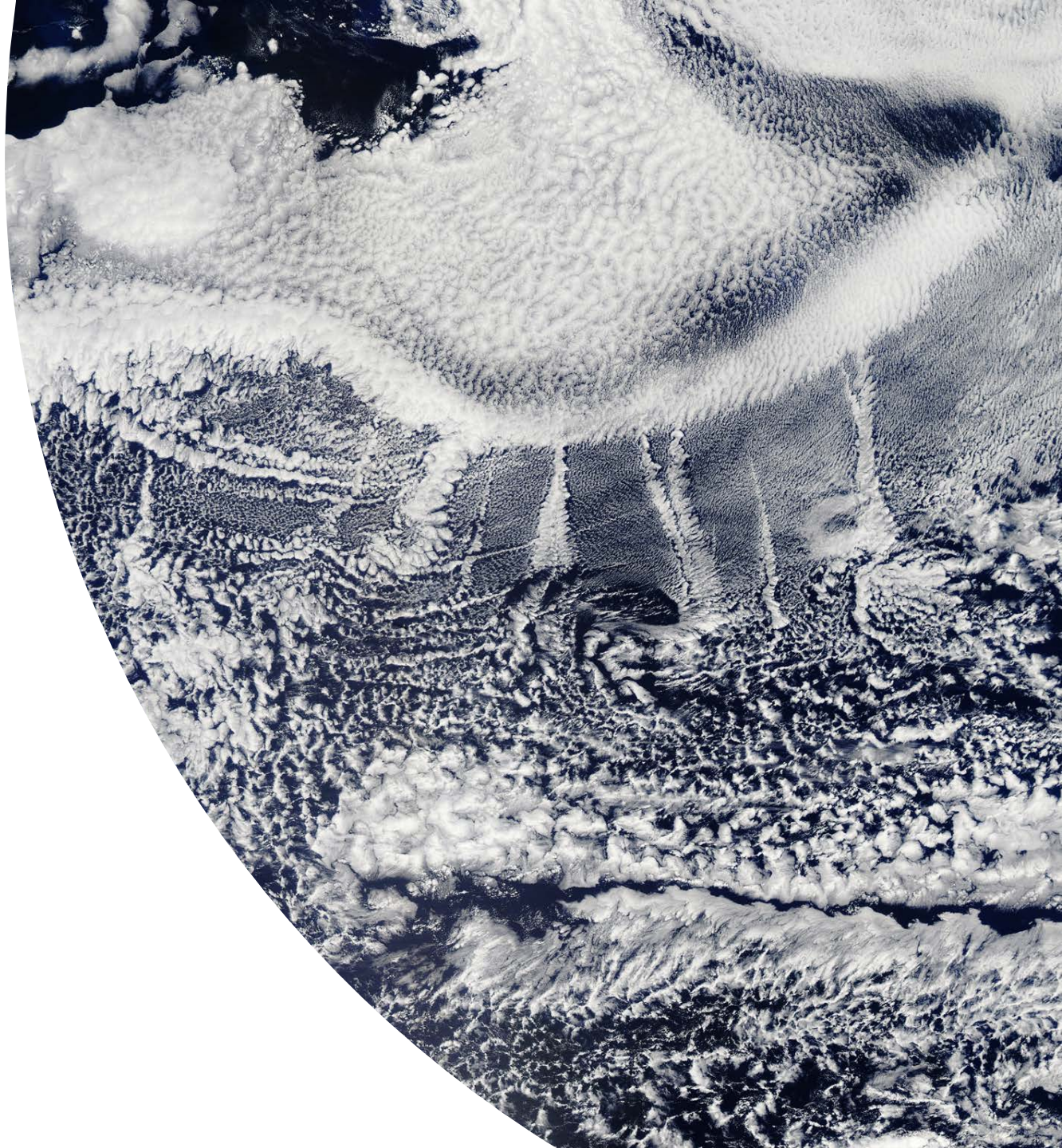


Elsaesser et al. (2017)



Methodology

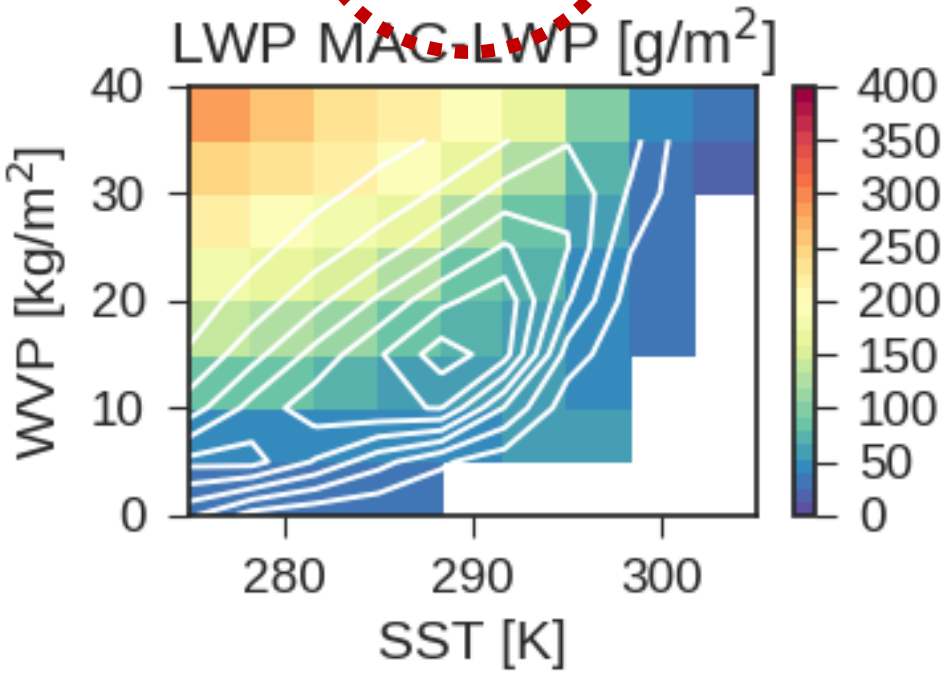
- Meteorology dominates the signal. Use multiple linear regression on predictors to try and partition covariance between LWP and meteorological and aerosol predictors.
- Data is resolved at 1°x1° and daily time resolution for 2003-2015 observations and 2012-2015 for simulations.
- Simulations are in UM GA7.1 (AKA HadGEM3-GC3.1, AR6 contribution) with fixed SST and N96 horizontal resolution.



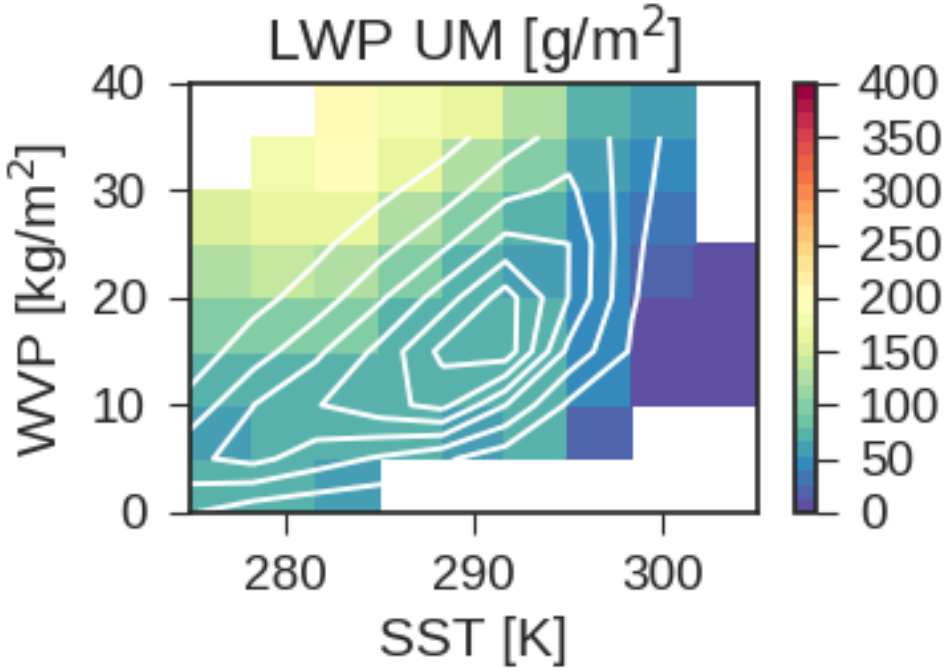
Methodology

- Bin data into SST-WVP space. Do multiple linear regression in data within each bin.

$$LWP = a_1 \ln(N_d) + a_2\omega_{550} + a_3 EIS + a_4 WVP + a_5 SST + a_6 SHF + a_7$$

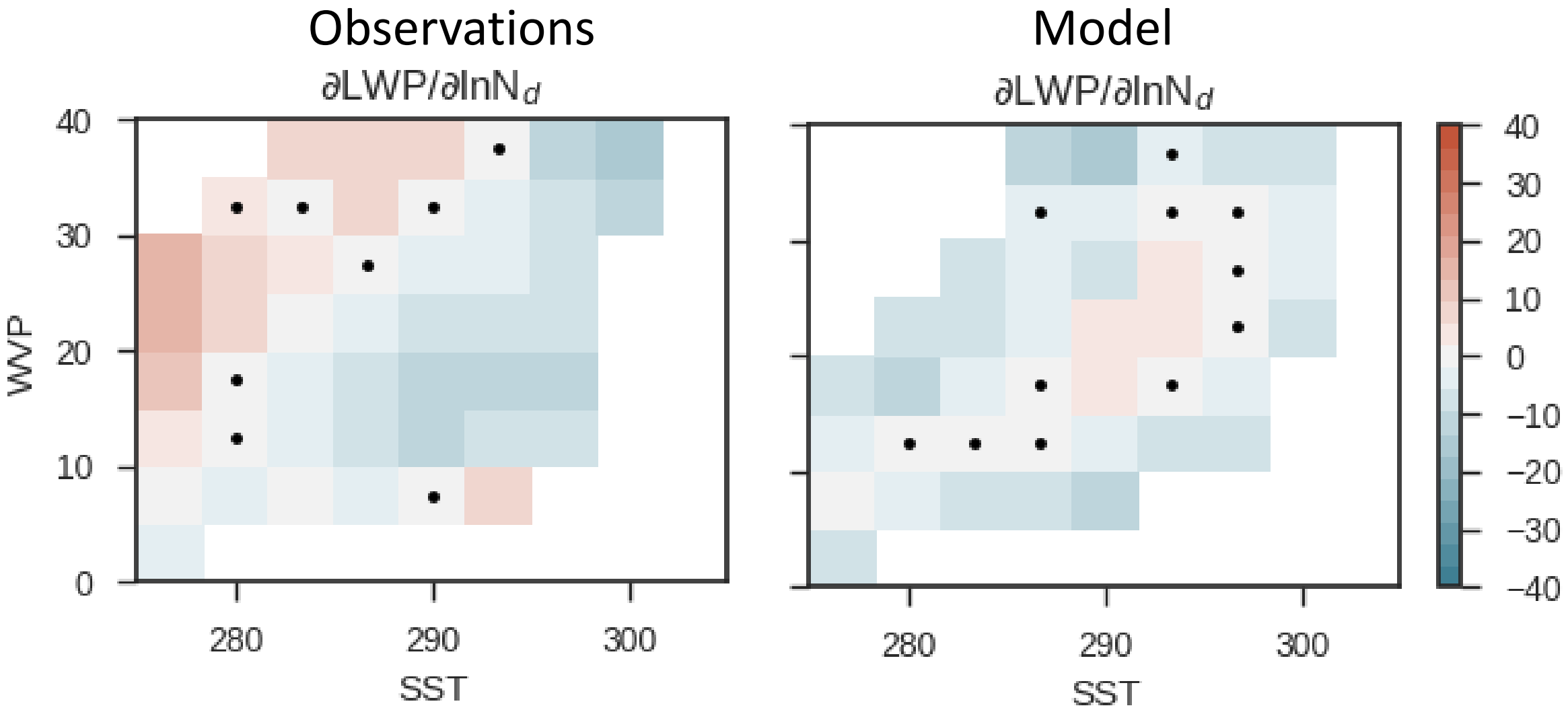


Observations



GCM

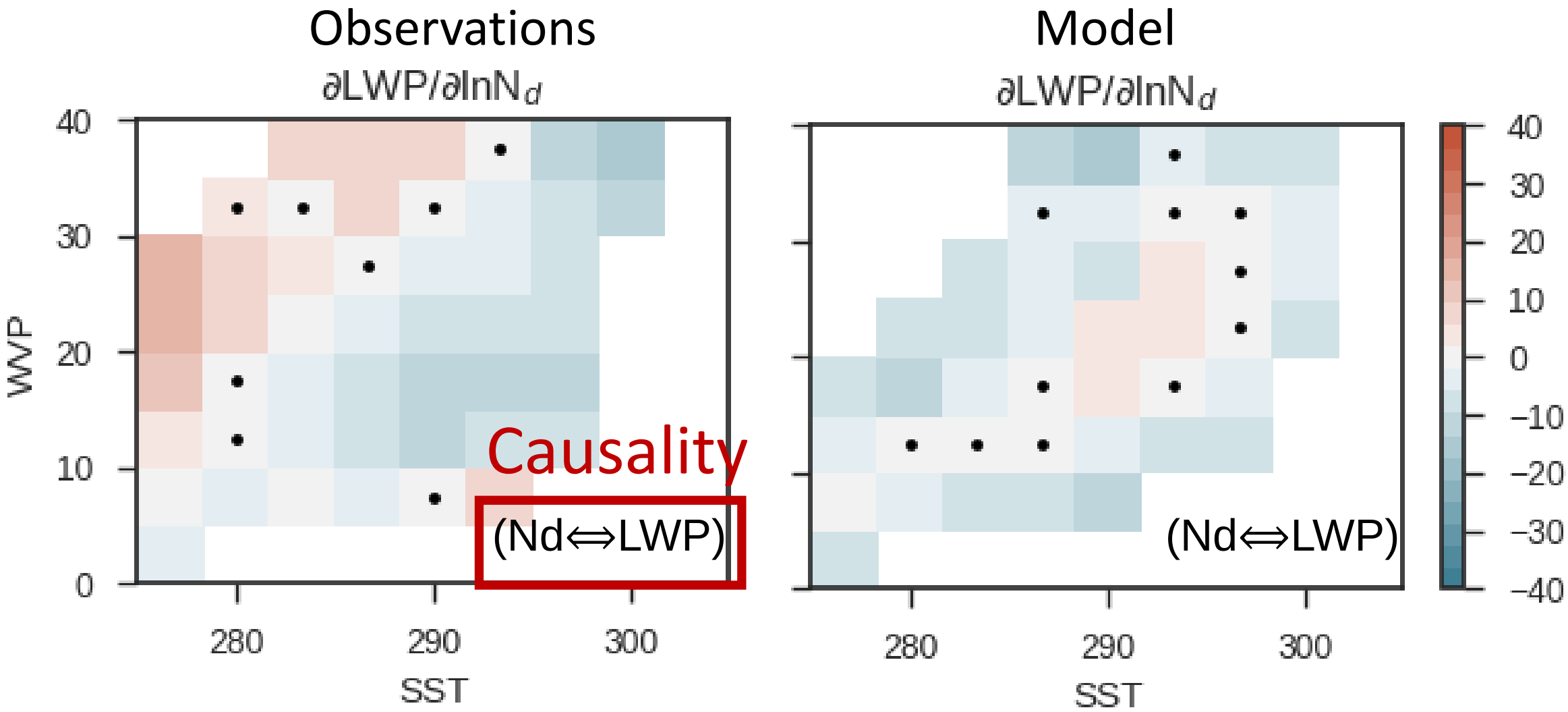
Covariance between Nd and LWP

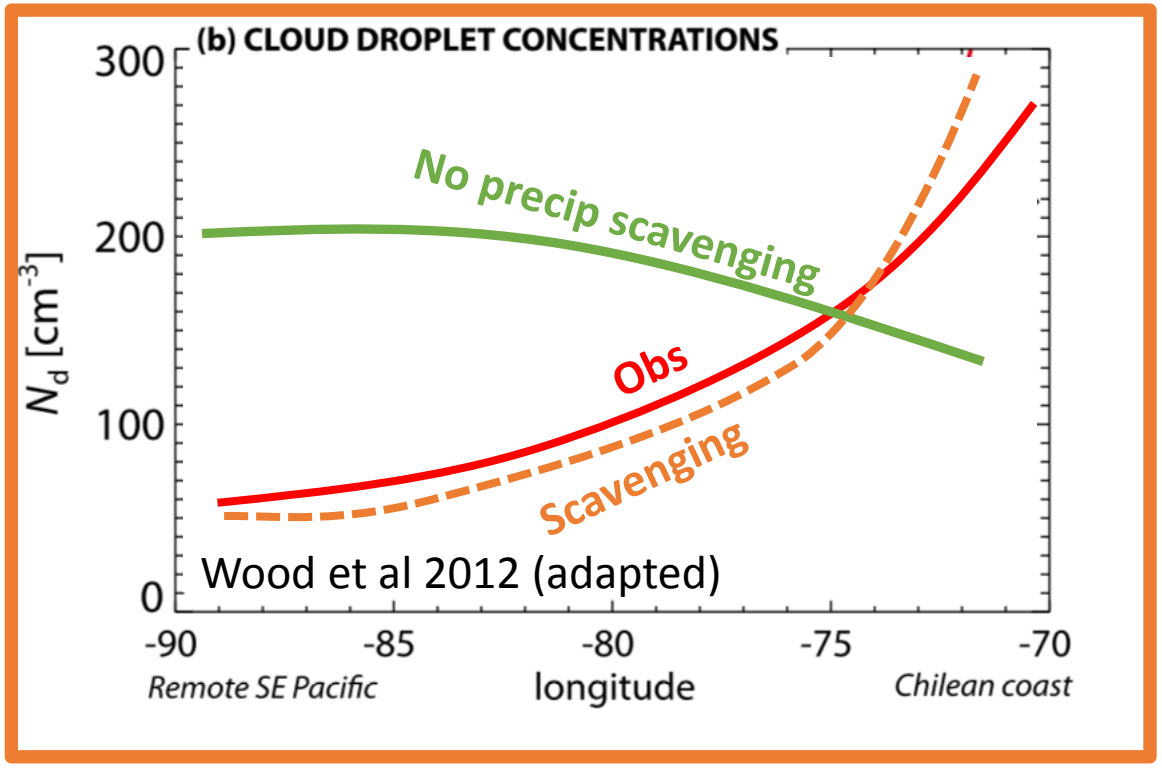


r(Nd,LWP)<0 - are adjustments dimming Earth?

No! Correlation is not causation!

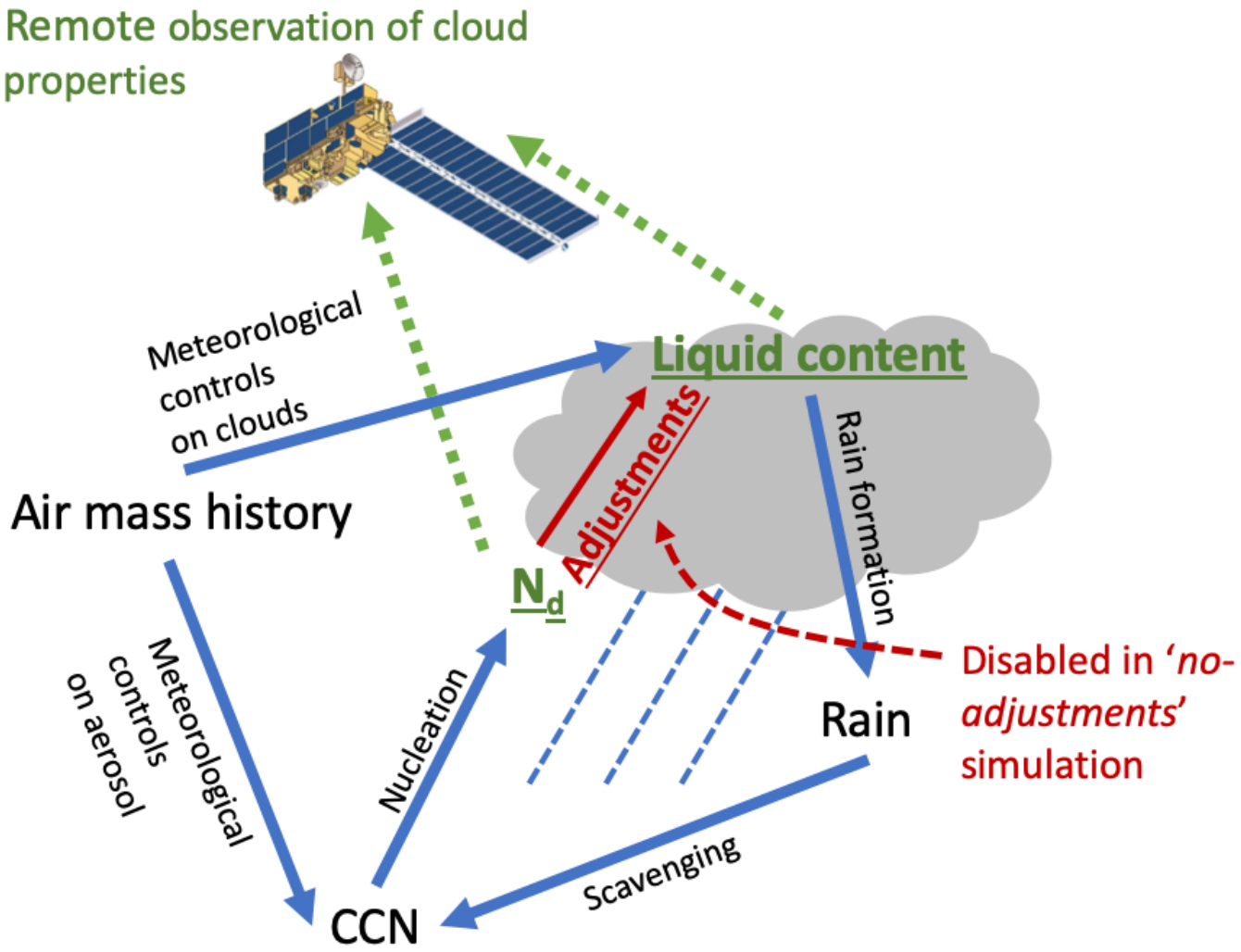
Covariance between Nd and LWP





Hypothesis: perturbations induced by non-adjustment processes and adjustment processes add linearly.

Adjustment strength can be inferred as the difference in ∂LWP/∂Nd between control and 'no-adjustments' simulations.

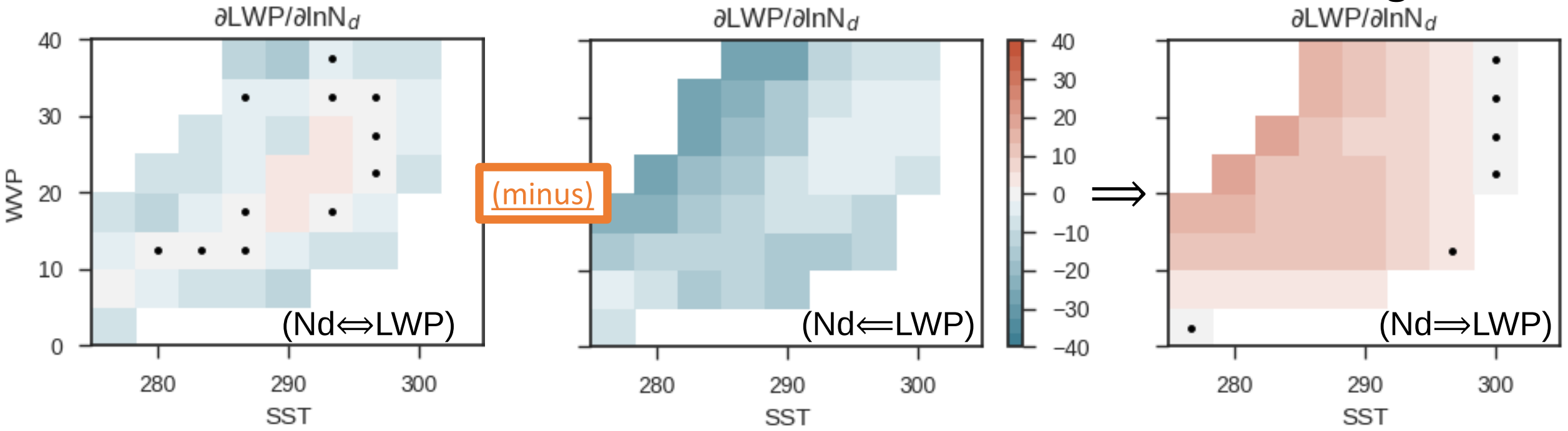


Inferring adjustment strength

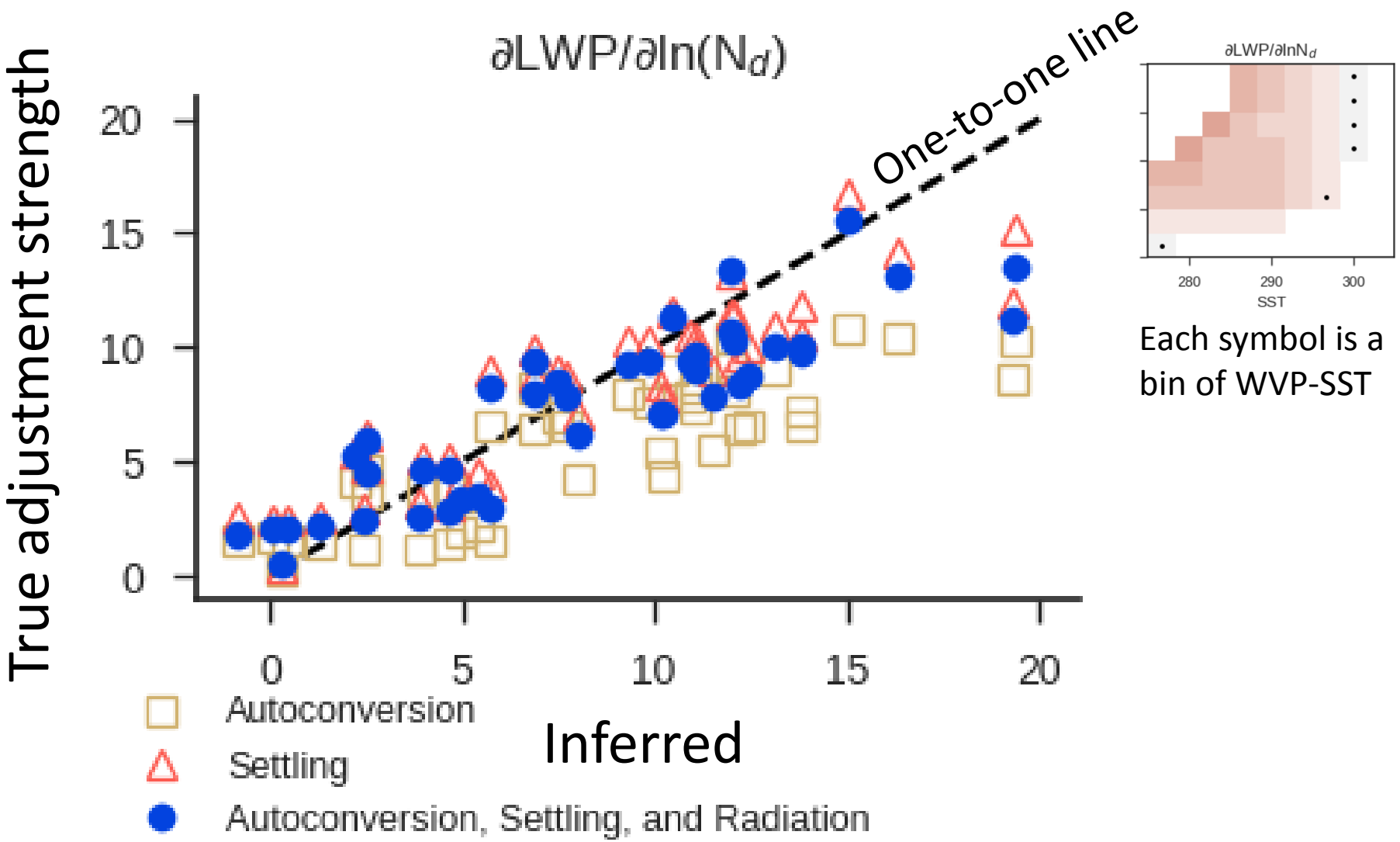
Control simulation

Nd does not affect cloud

Inferred adjustment strength



Test1: Can we reconstruct the model behavior?



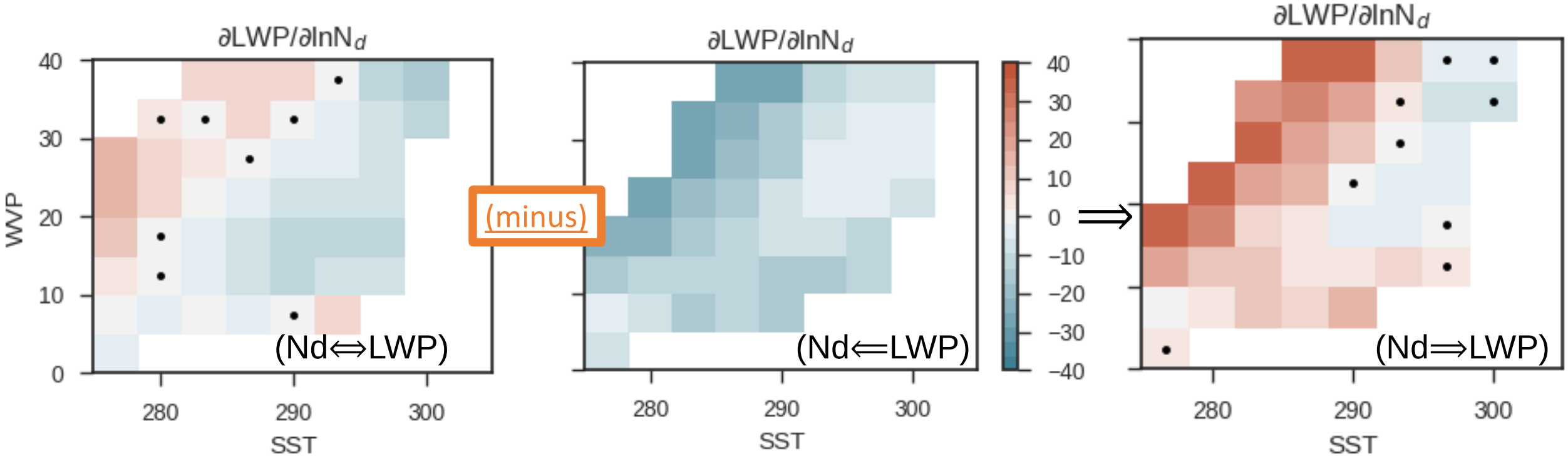
Each symbol is a bin of WVP-SST

Inferring adjustment strength (Obs)

Observations

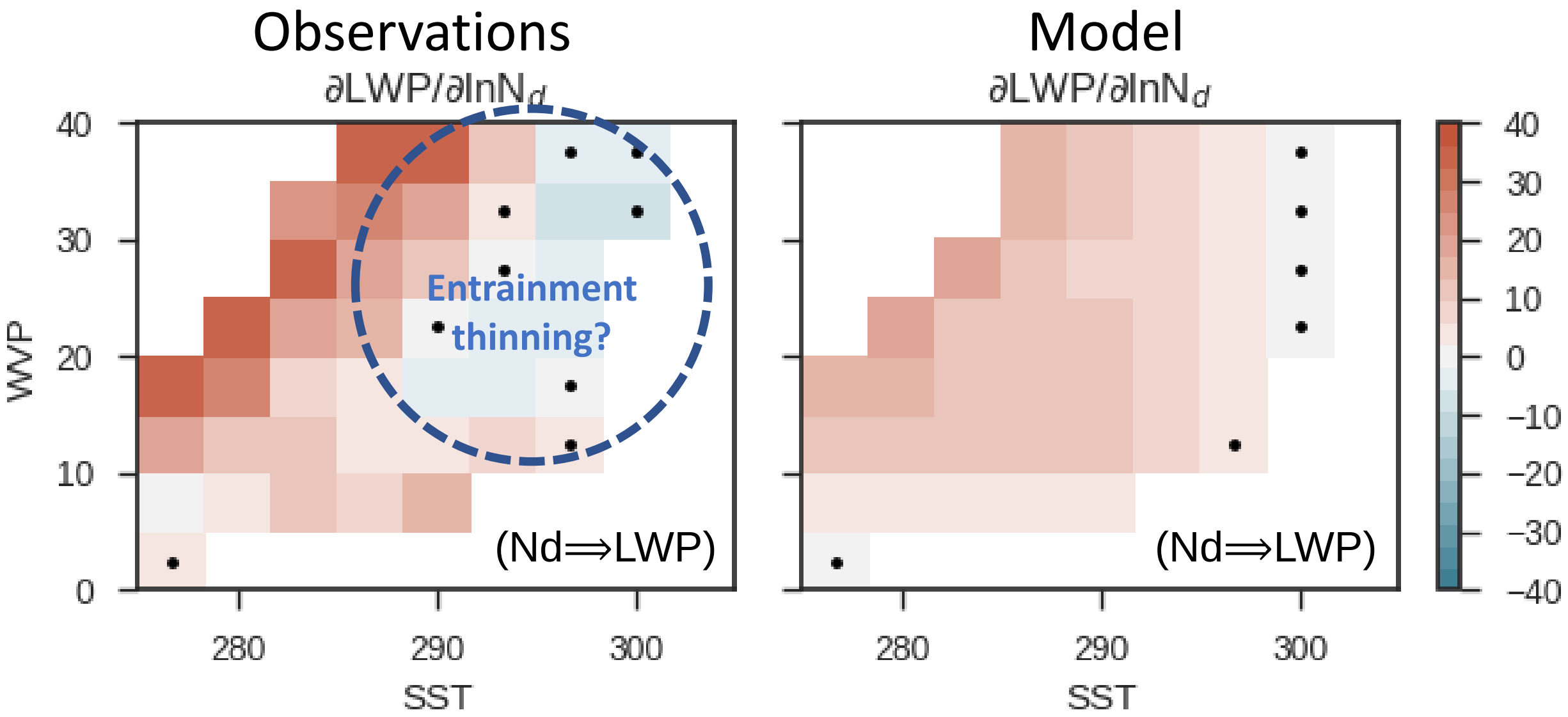
Nd does not affect cloud

Inferred adjustment strength



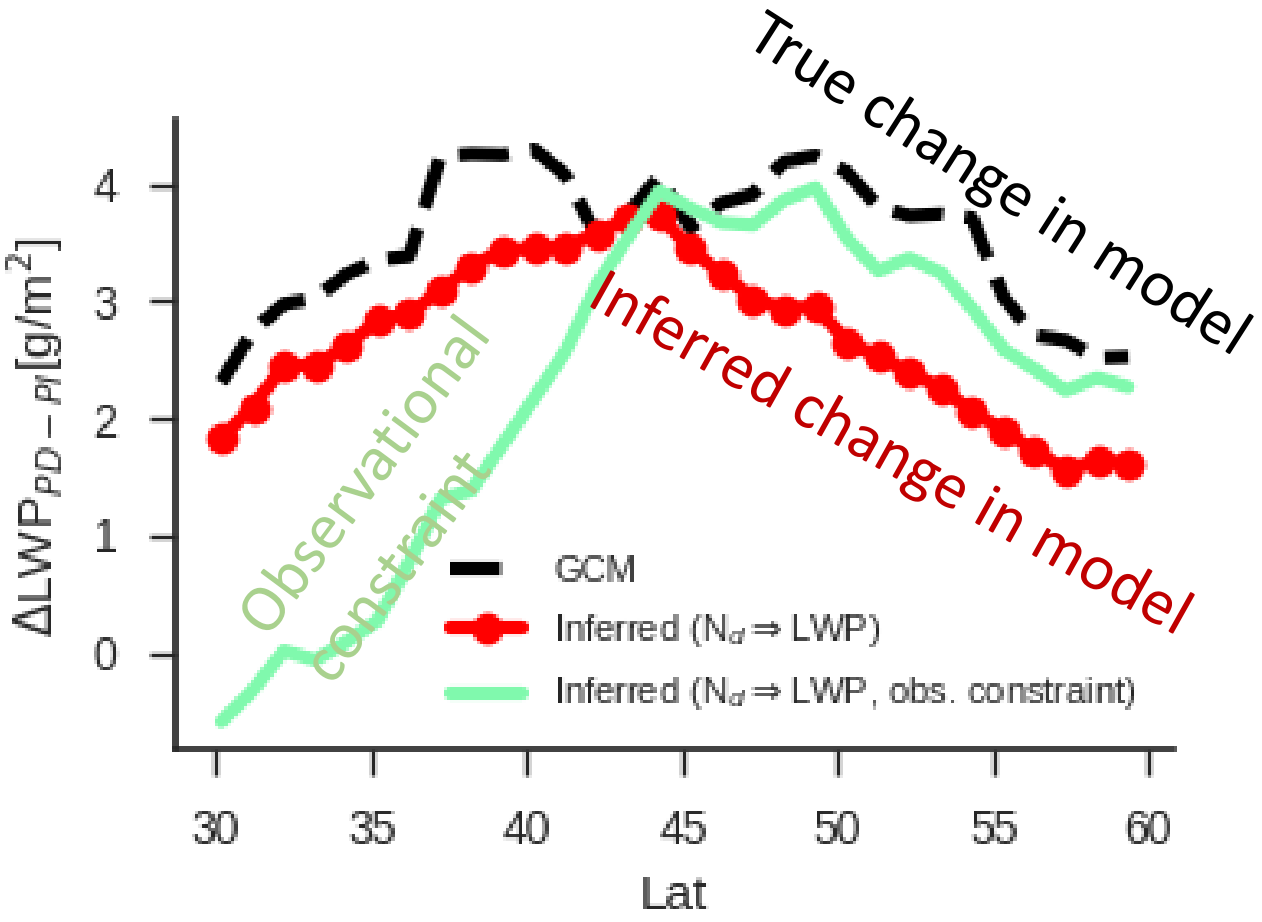
Caveat: assumes model represents none-adjustment processes accurately.

Inferred adjustments in observations



Test2: can we predict PI-PD ΔLWP?

- Simulation rerun with PI emissions. Contrast true $\Delta LWP_{PI\text{-}PD}$ with predicted $\Delta LWP_{PI\text{-}PD}$ based on this method and the $\Delta Nd_{PI\text{-}PD}$.
- Projected brightening of ~1 Wm^{-2} (in NH storm tracks outside of cyclones) based on LWP-albedo relationship in model and observations.



Summary

- Just looking at covariance between LWP and Nd shows negative covariability.
- Spurious due to scavenging and air mass history.
- Removing non-adjustment covariability inferred by models shows that LWP increases in response to Nd about the right amount in HadGEM3-UKCA (*consistent with Malavelle et al. [2017] volcano paper).

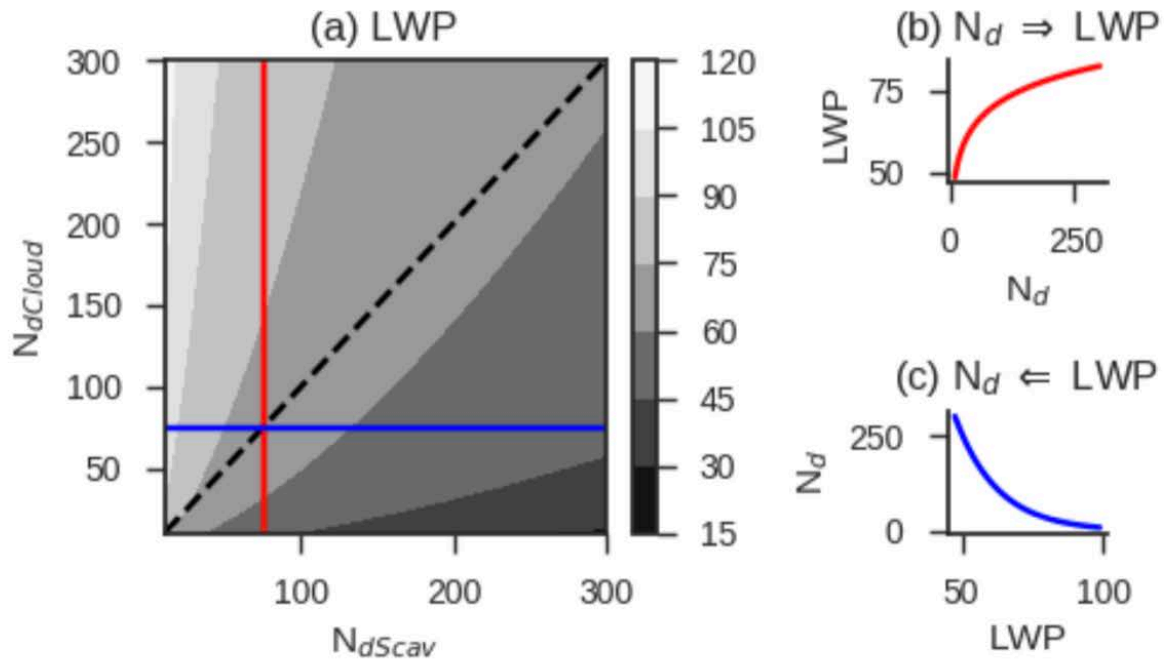
Data requirement:

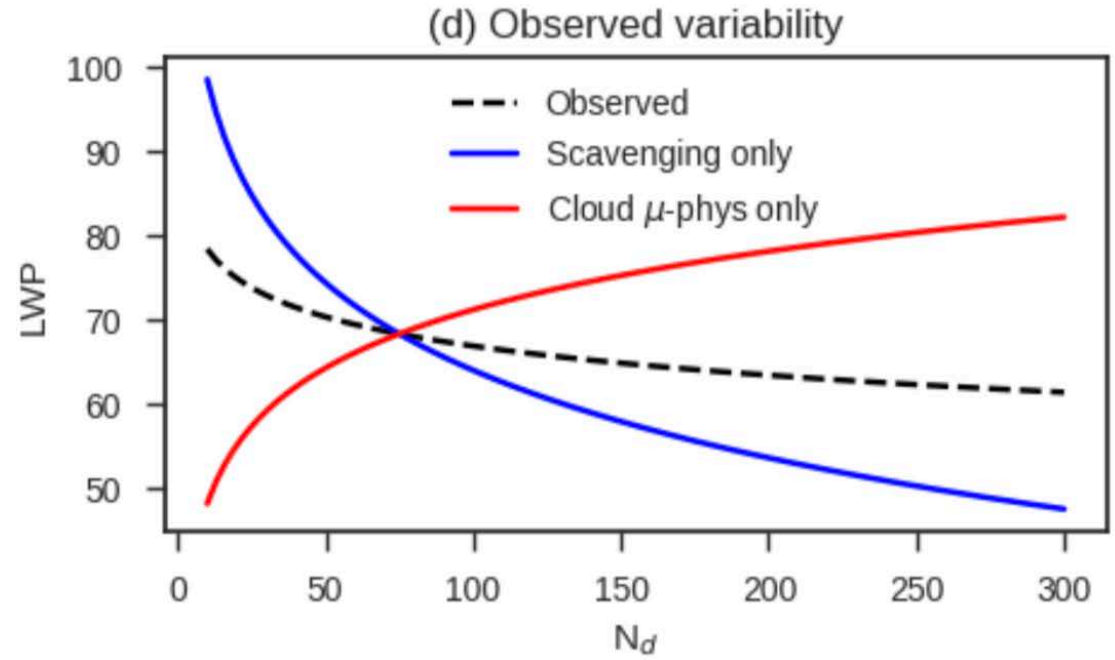
- Daily-means
- LWP, Nd, 10m wind speed, subsidence at 550hPa, EIS, WVP, SST, SHF

Simulations:

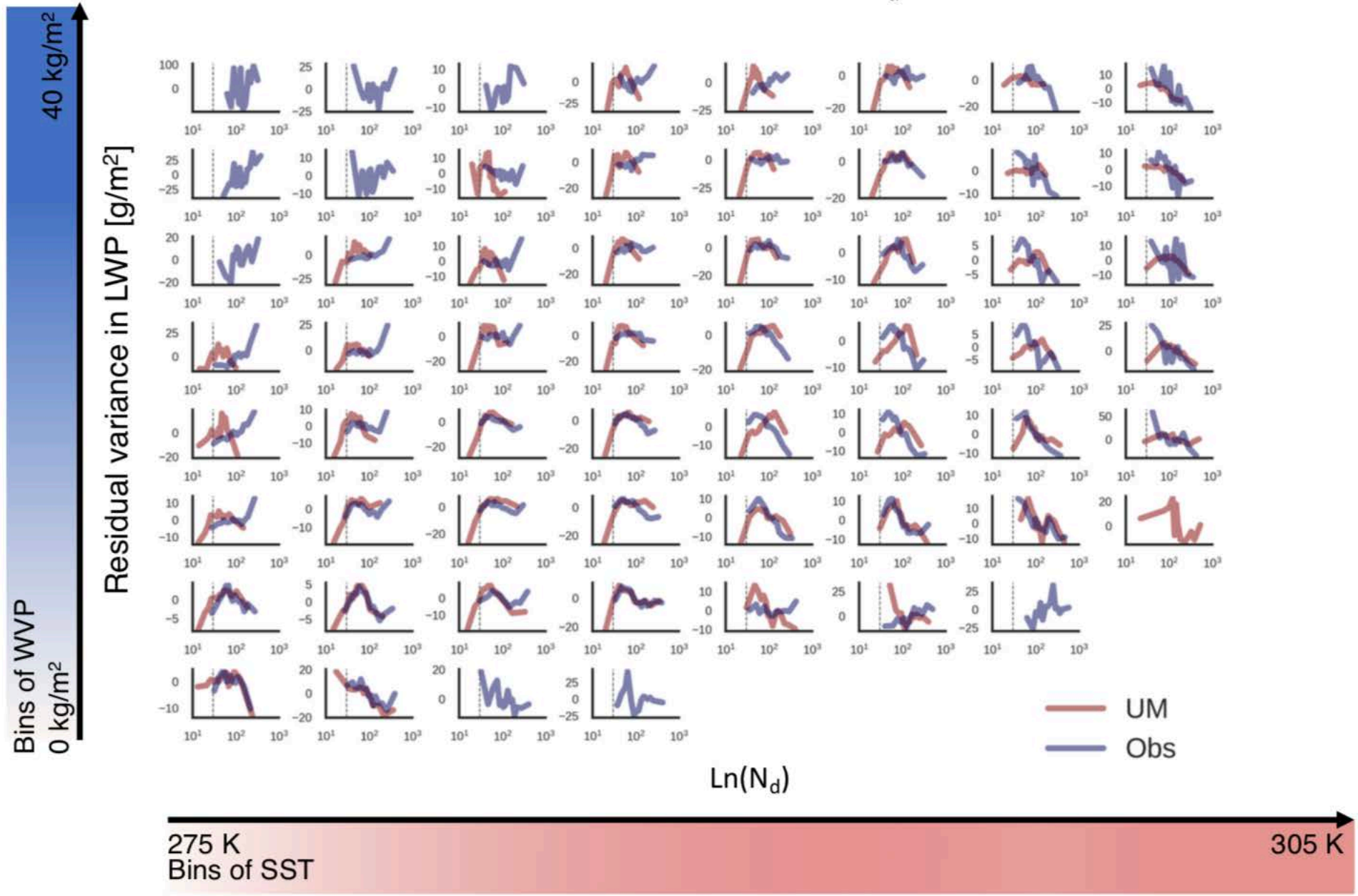
- 3 years of simulations in PI and PD
- Control simulation
- No-adjustments simulation (set Nd=75cm^{-3} in microphysics)

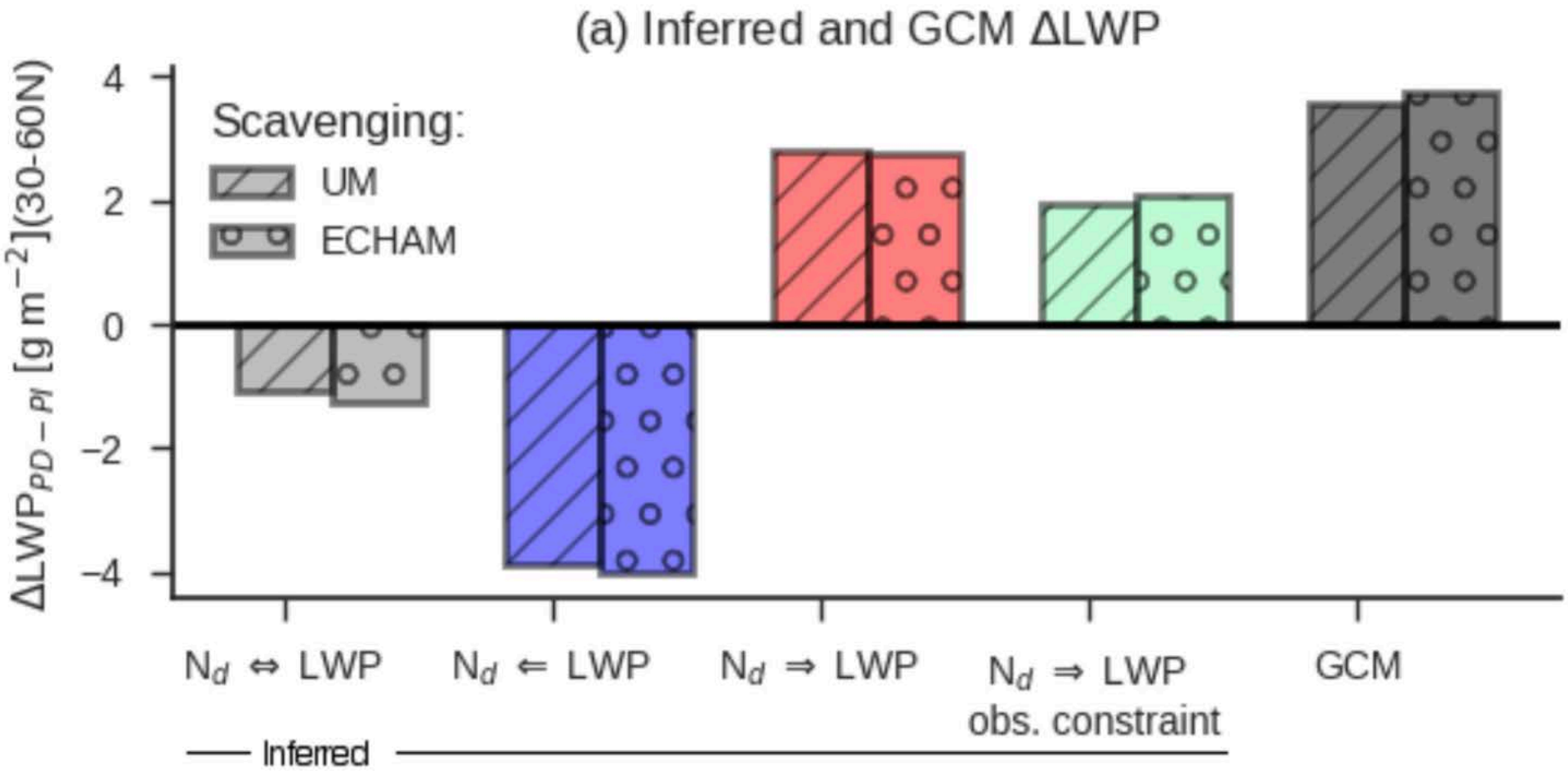
Contact me if you'd be interested in analyzing your model!

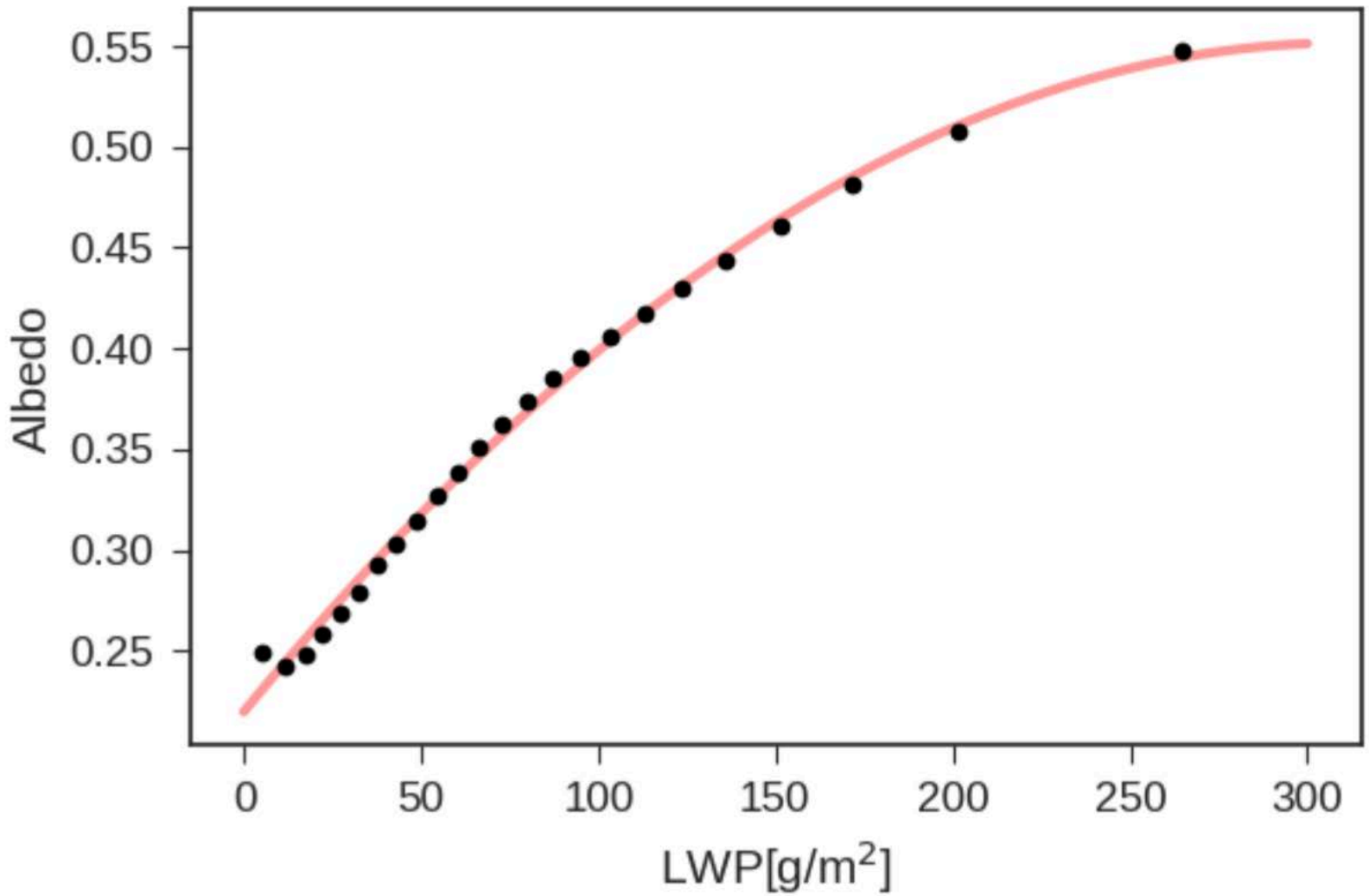

(a) LWP
300
250
200
150
100
50
N_{dCloud}
100
200
300
N_{dScav}
120
105
90
75
60
45
30
15
(b) N_d ⇒ LWP
LWP
75
50
0
250
N_d
(c) N_d ⇐ LWP
N_d
250
0
50
100
LWP


(d) Observed variability
Observed
Scavenging only
Cloud μ-phys only
LWP
100
90
80
70
60
50
0
50
100
150
200
250
300
N_d

Residual variance in LWP as a function of N_d in bins of SST and WVP



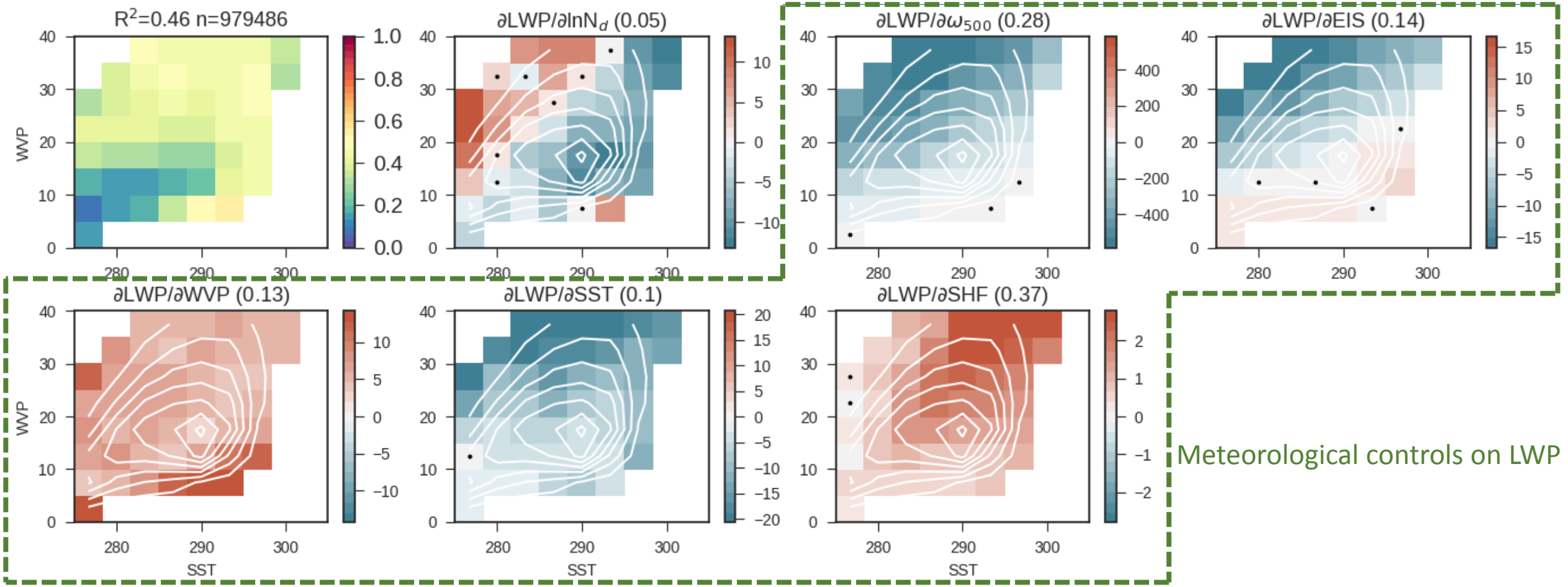

(a) Inferred and GCM ΔLWP
ΔLWP$_{PD-PI}$ [g m^{-2}](30-60N)
4
2
0
−2
−4
Scavenging:
UM
ECHAM
N$_d$ ⇔ LWP
N$_d$ ⇐ LWP
N$_d$ ⇒ LWP
N$_d$ ⇒ LWP
obs. constraint
GCM
Inferred


0.55
0.50
0.45
0.40
0.35
0.30
0.25
Albedo
0
50
100
150
200
250
300
LWP[g/m^2]

Observed covariances (NH)

$$LWP = a_1 \ln(N_d) + a_2 \omega_{550} + a_3 EIS + a_4 WVP + a_5 SST + a_6 SHF + a_7$$

Diagnostic of adjustments (?)

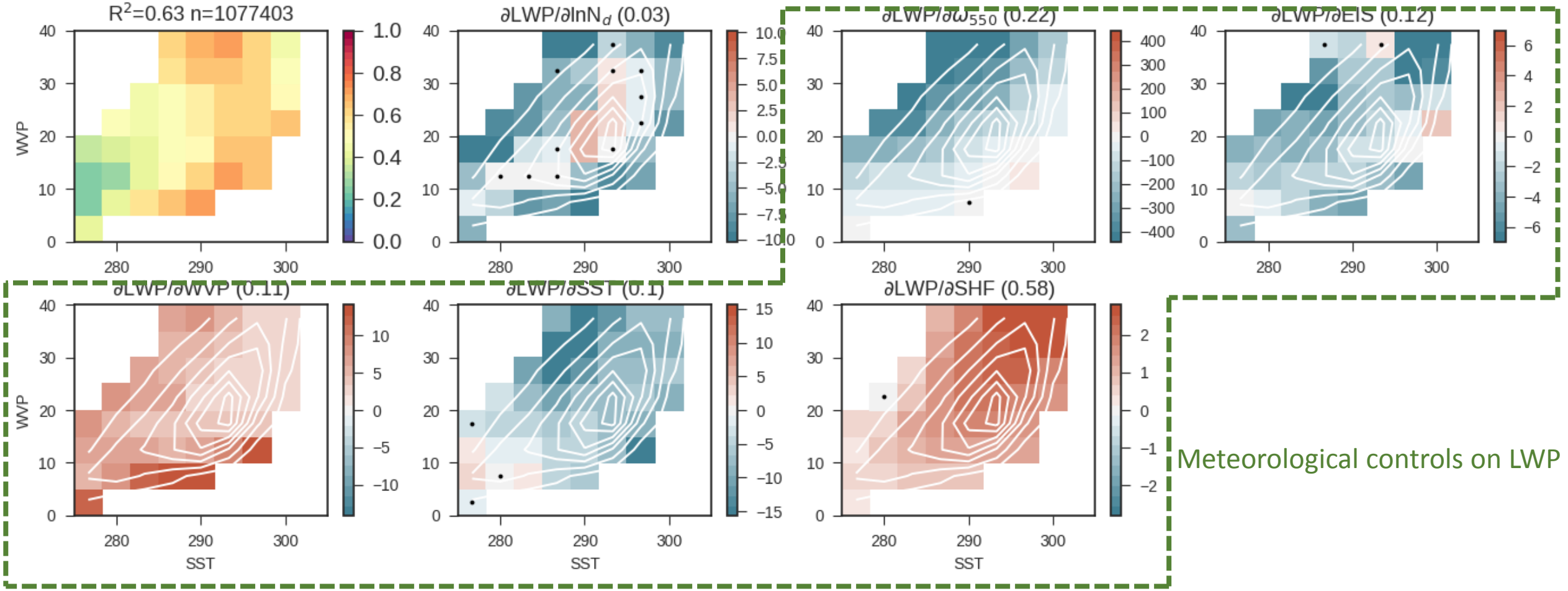


Meteorological controls on LWP

Model covariances (NH)

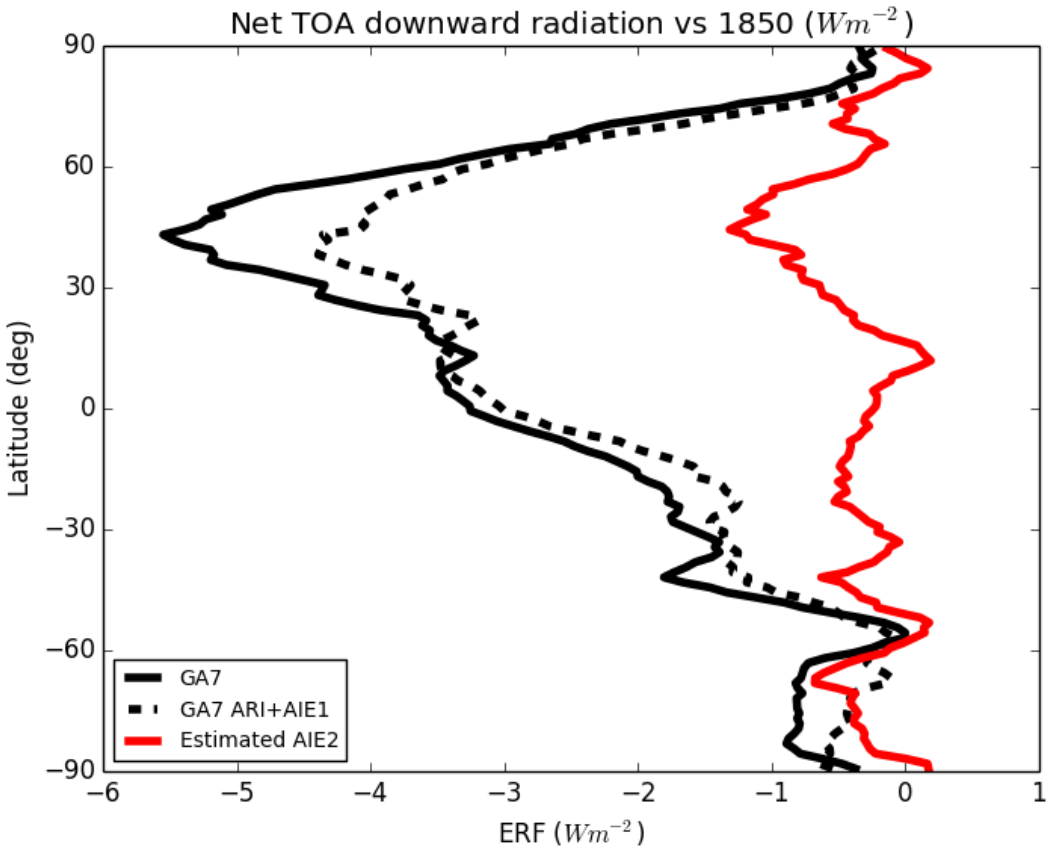
$$LWP = a_1 \ln(N_d) + a_2 \omega_{550} + a_3 EIS + a_4 WVP + a_5 SST + a_6 SHF + a_7$$

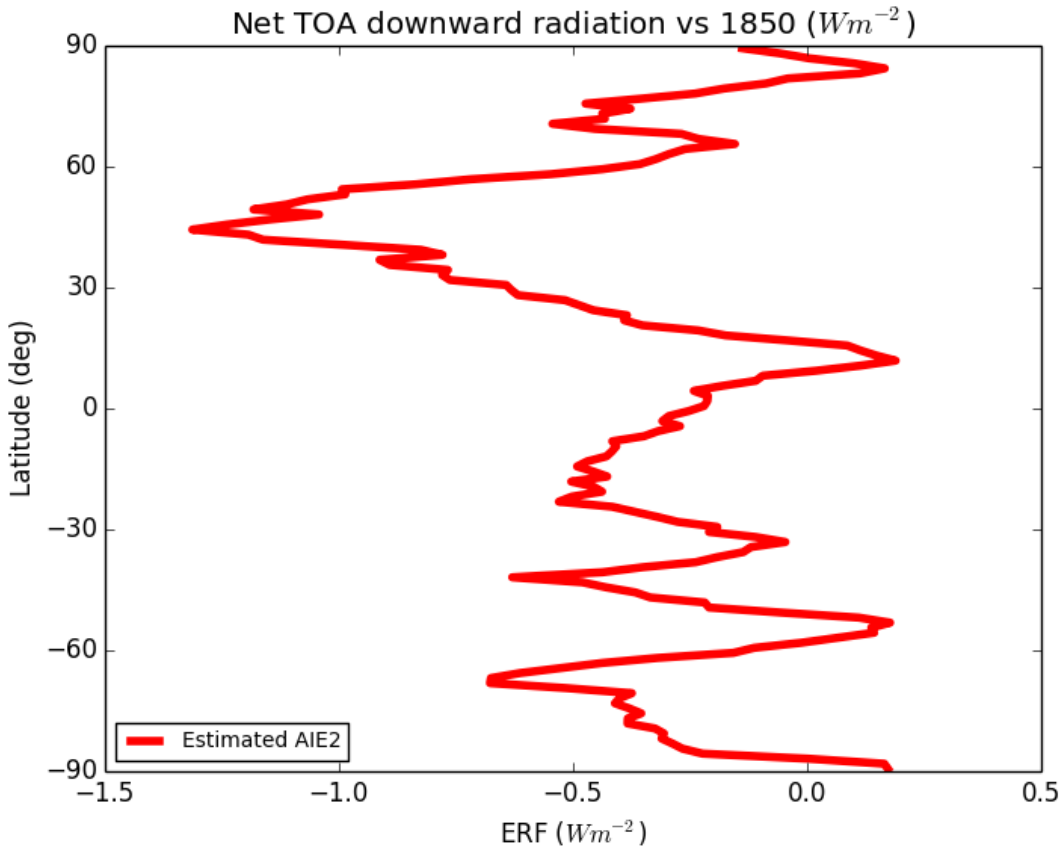
Diagnostic of adjustments (?)



Meteorological controls on LWP

Estimated GA7 adjustment forcing (courtesy of Jane Mulcahy from Mulcahy et al. 2018)





Global-mean ~ -0.4 Wm^{-2}, note GA7.1 has much lower RFaci (-1.45 Wm^{-2} vs -2.75 Wm^{-2}).