Examining state dependence of the cloud feedback using a perturbed parameter ensemble

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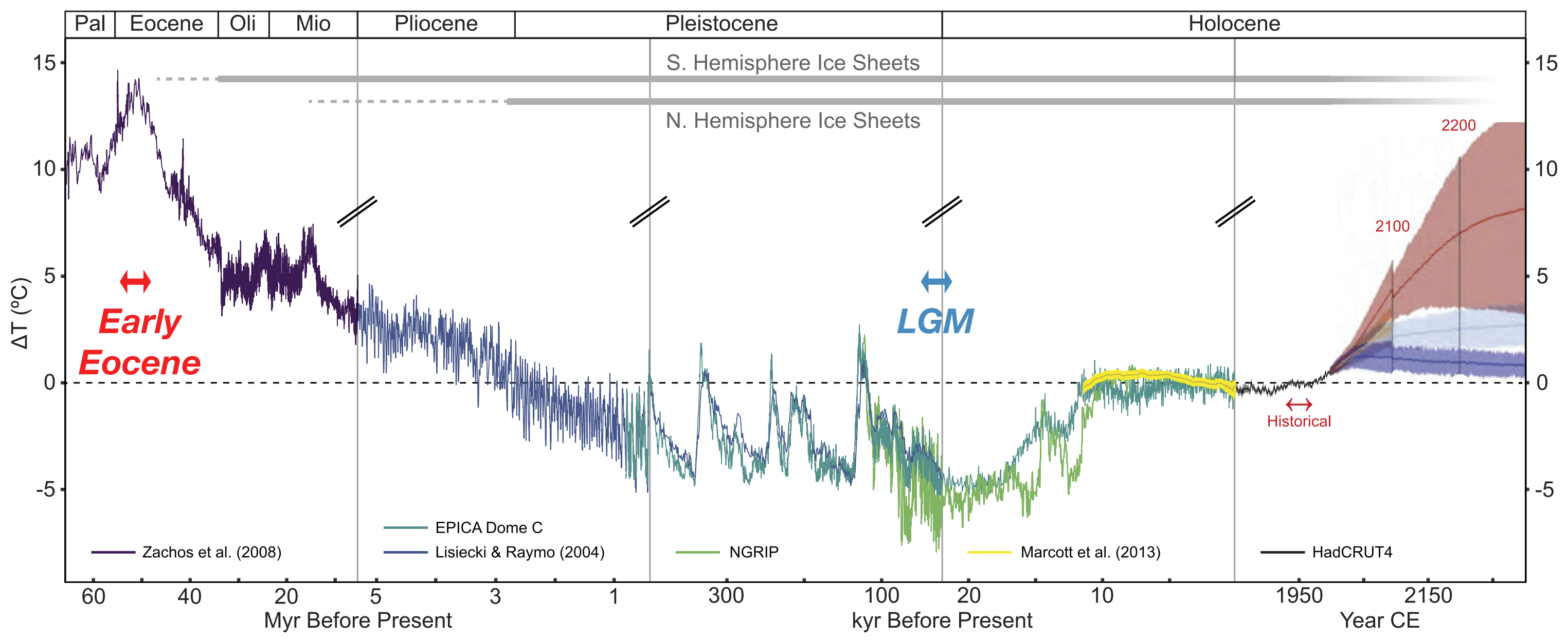
I. Motivation



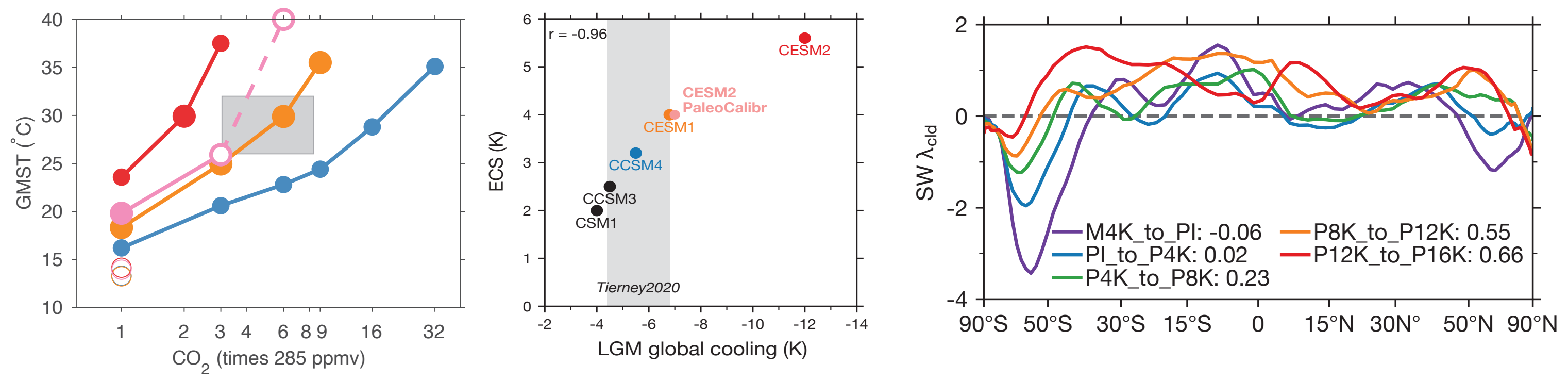
Burke et al., 2018, *PNAS*

1. Past climates inform our future; understanding of the state and forcing dependent response is critical.

- *How does the cloud feedback depend on climate states? Are there non-linear tipping points?*
- How does the cloud feedback interact with temperature and its spatial pattern?

2. Past climates inform the equilibrium climate sensitivity (ECS) in models.

- Community Earth System Model v2 (CESM2) fails to simulate the Last Glacial Maximum (LGM) & the early Eocene (EECO): its high ECS (>5°C) is unrealistic
- An LGM-calibrated CESM2 still fails to simulate the Early Eocene
- *Which processes/parameters control the nonlinear cloud feedback (λ_{cld})?*



Zhu et al., 2019, *Sci. Adv.*
Zhu, et al., 2020, *Nat. Clim. Change.*

Zhu et al., 2017, *GRL*
Zhu et al., 2021, *GRL*
Zhu, et al., 2022, *JAMES*

2. Approach: perturbed parameter ensemble (PPE)

1. Community Atmosphere Model v6 (CAM6) in ~2°

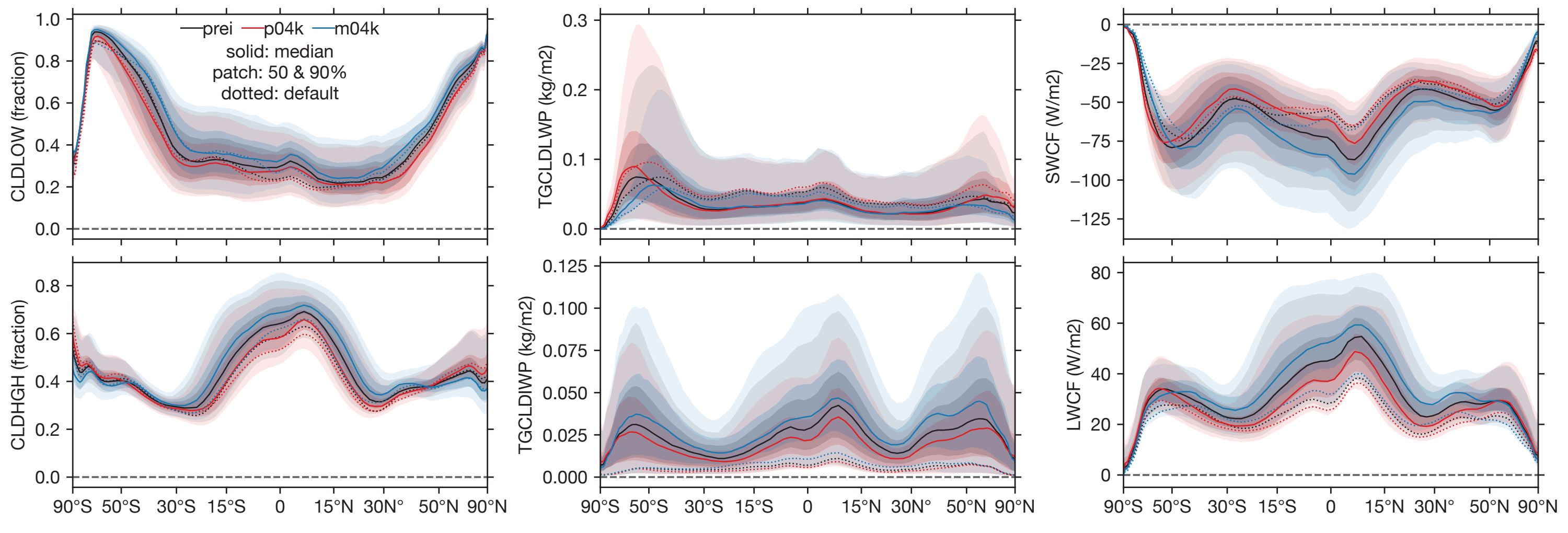
- PaleoCalibr fixes: no cloud-ice-number-limiter (nimax); shorter microphysical Δt

2. PPE setup

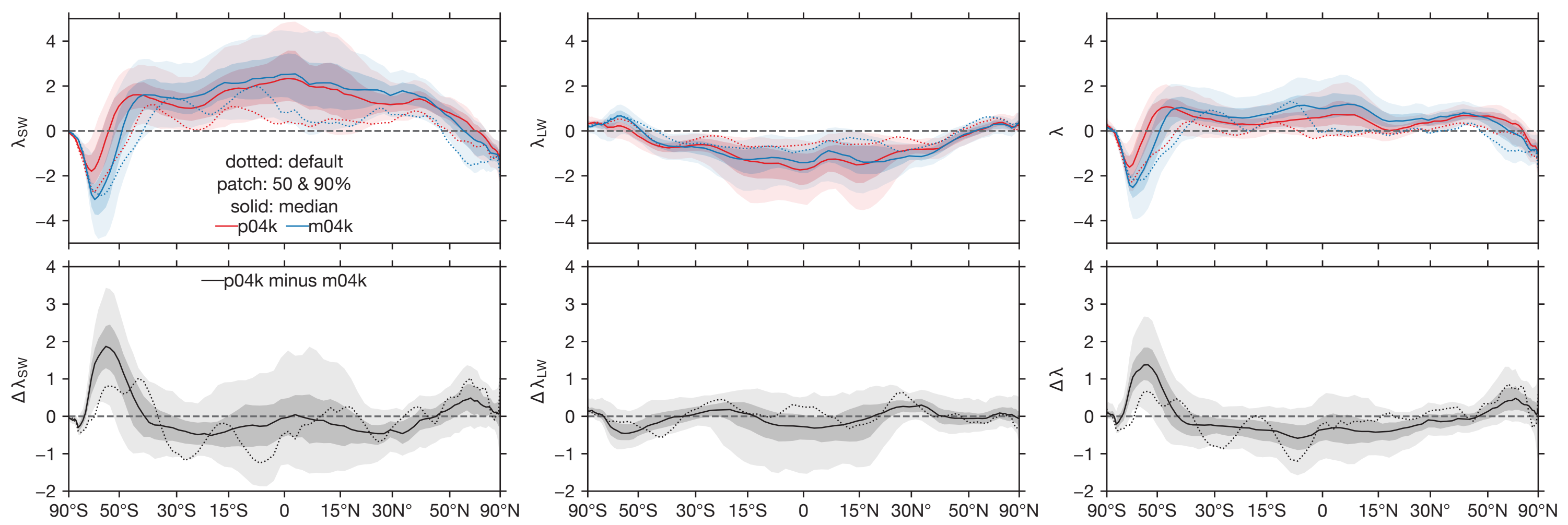
- 45 parameters in convection & cloud parameterizations (see below for a subset)
- 250 ensemble simulations (5 years each) from Latin Hypercube sampling
- Preindustrial SST (*prei*) and SST+4K (*p04k*) & –4K (*m04k*) with uniform change
- *Future plans*: SST+8K, +12K,+16K, & patterned warming

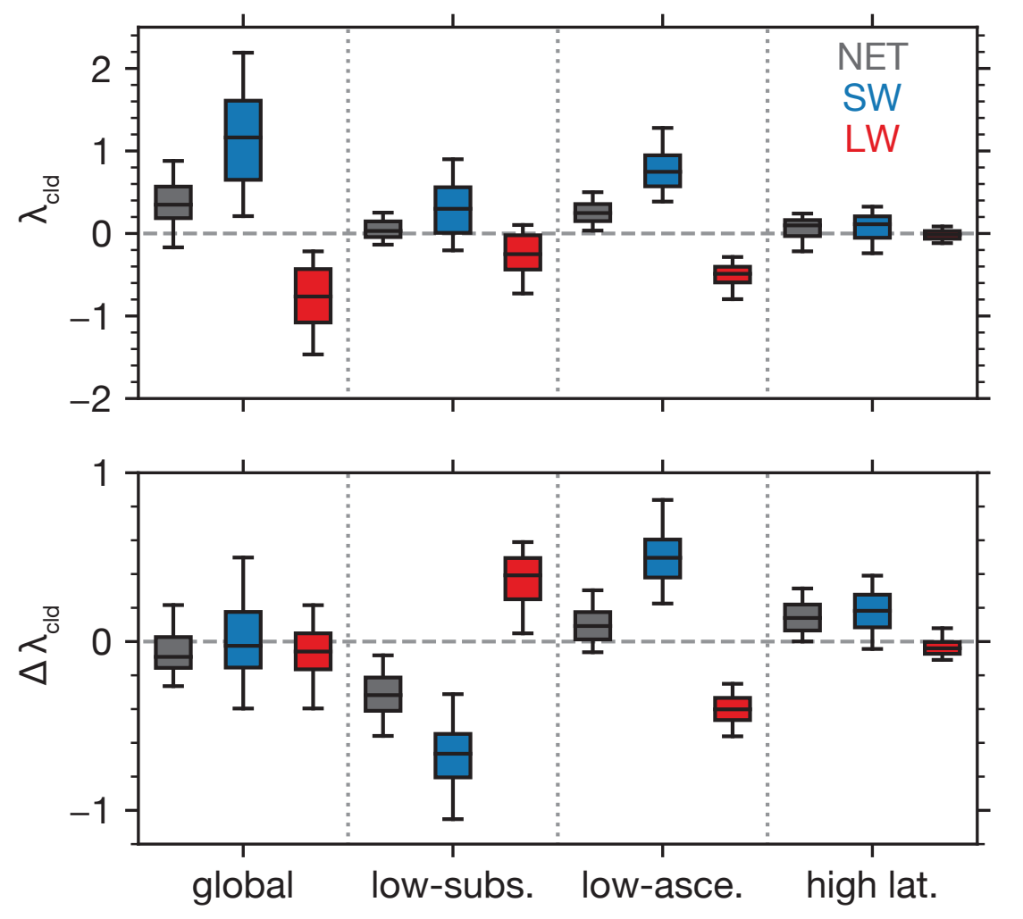
Physics	*Parameter Name*	*Description*	*Default*	*Min*	*Max*
CLUBB	clubb_c1	Low Skewness in C1 Skw.	1	0.4	3
	clubb_C2rt	Damping on scalar variances	1	0.2	2
	clubb_C8	Coef. #1 in C8 Skewness Equation	4.2	1	7
	clubb_c11b	High Skewness in C11 Skw	0.35	0.2	0.8
	clubb_c14	Constant for u'^2 and v'^2 terms	2.2	0.4	4
MG3	micro_mg_accre_enhan_fact	Accretion enhancing factor	1	0.1	10
	micro_mg_berg_eff_factor	Bergeron efficiency factor	1	0.1	1
	micro_mg_autocon_lwp_exp	KK2000 LWP exponent	2.47	2.1	3.3
	micro_mg_dcs	Autoconversion size threshold ice-snow	2.00E-04	5.00E-05	1.00E-03
	micro_mg_vtrmi_factor	Ice fall speed scaling	1	0.2	5
ZM	zmconv_dmpdz	Parcel fractional mass entrainment rate	-1.00E-03	-2.00E-03	-2.00E-04
	cldfrc_dp1	Parameter for deep convection cloud fraction	0.1	0.05	0.25
	zmconv_tiedke_add	Convective parcel temperature perturbation	0.5	0	2
	zmconv_capelmt	Triggering threshold for ZM convection	70	35	350
Aerosol	microp_aero_wsub_scale	Subgrid velocity for liquid activation scaling	1	0.1	5

3. Results: asymmetrical response to warming/cooling



PPE generates a wide range of cloud states & feedbacks

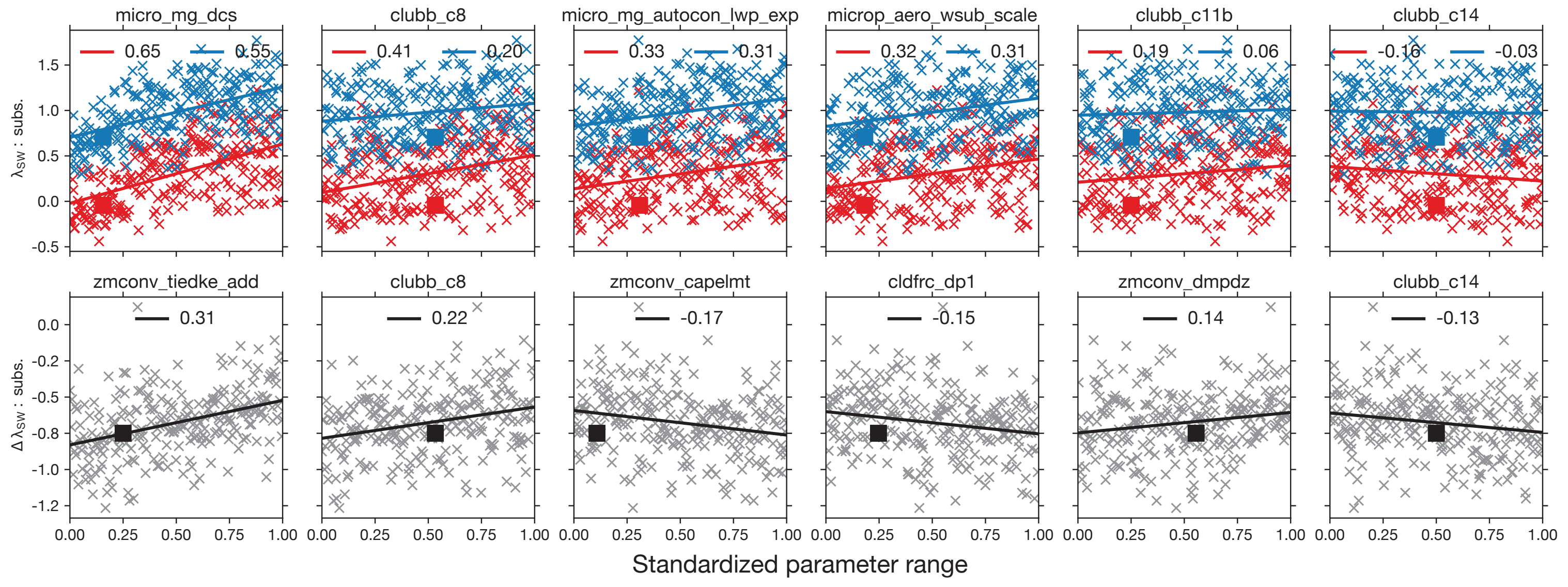




Compared to cooling, warming has

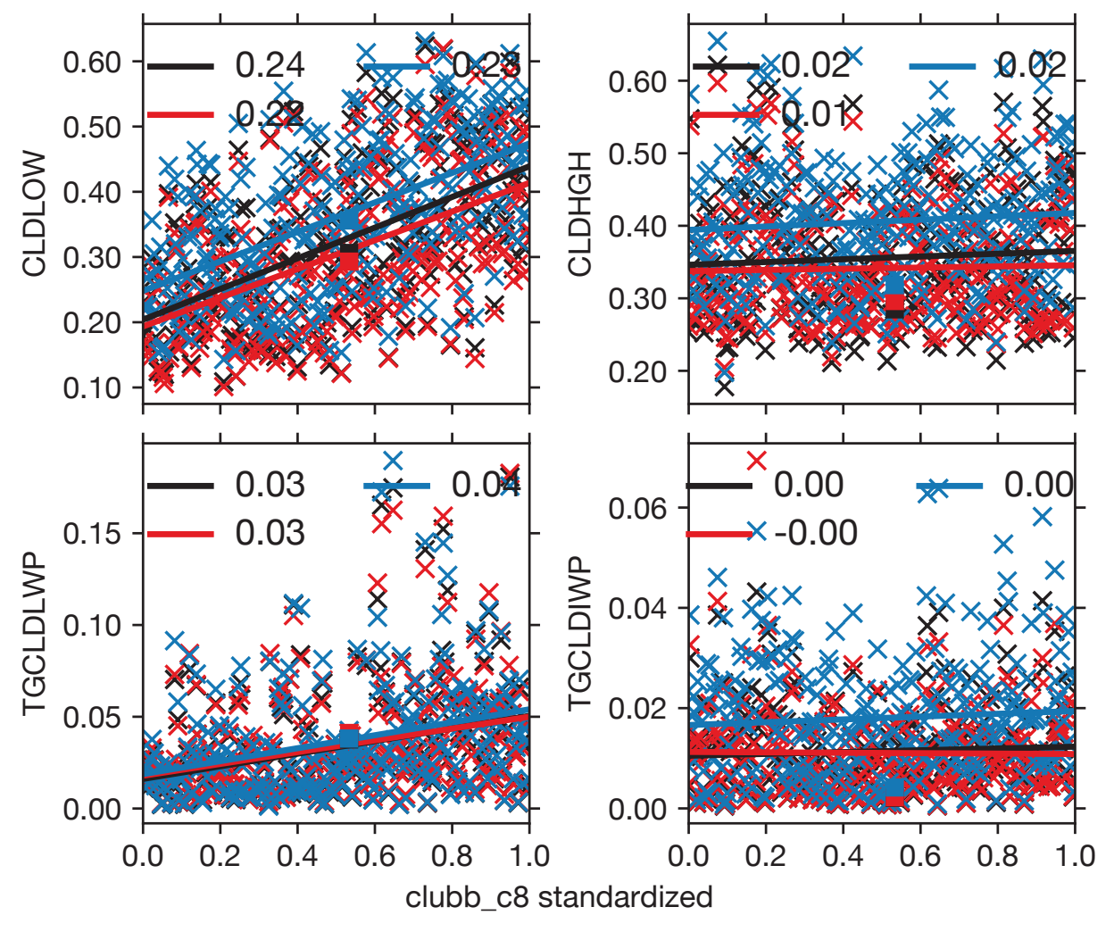
1. more negative SW λ_{cld} over low-lat. subsidence regime ($\omega_{500}>0$ & $|lat|<40^\circ$);
2. more positive SW λ_{cld} over low-lat. ascending regime ($\omega_{500}<0$ & $|lat|<40^\circ$); and
3. more positive SW λ_{cld} over high-lat. regime ($|lat|>40^\circ$).

Cancellation between LW & SW components, and between cloud regimes

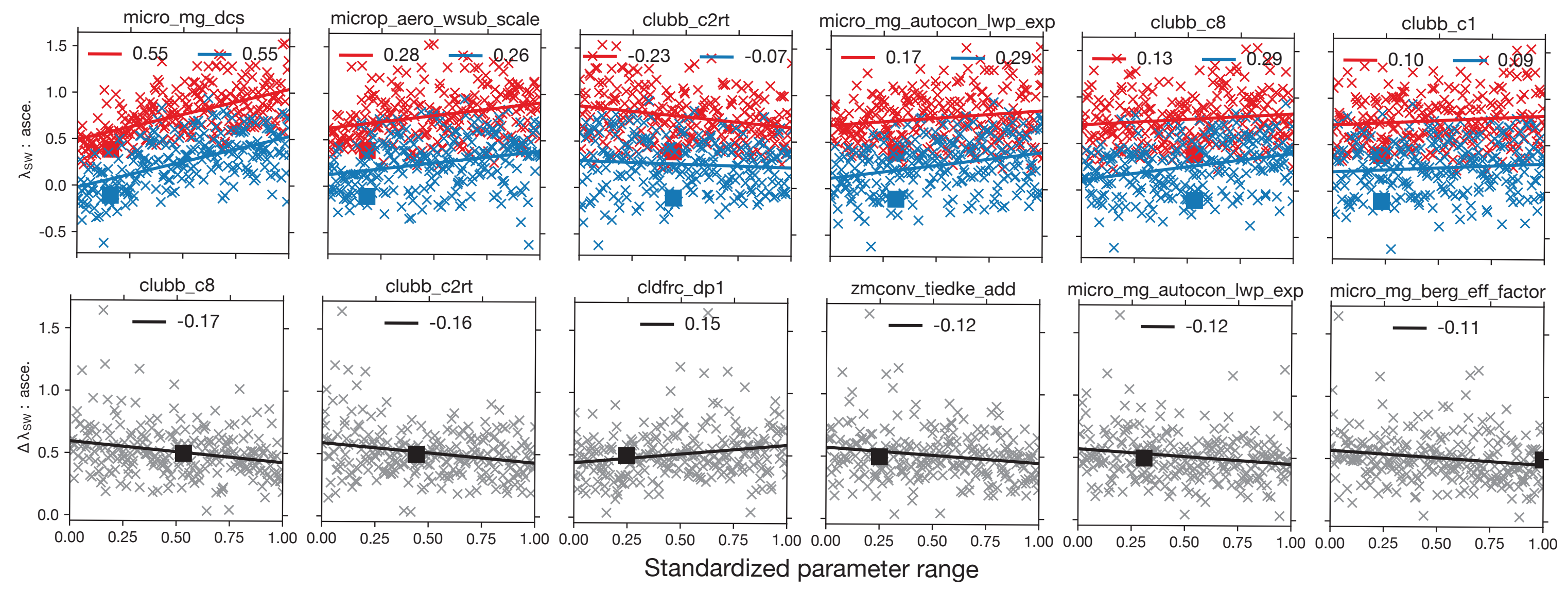


Over the low-lat. subsidence regime, moist turbulence & deep convection have the strongest impact on the SW λ_{cld} nonlinearity

1. Role of the background stratocumulus (sc) fraction: larger clubb_c8 –> stronger damping on $\overline{w'^3}$ –> clouds more sc-like –> stronger λ_{cld}
2. Role of the background low-tropospheric stability?

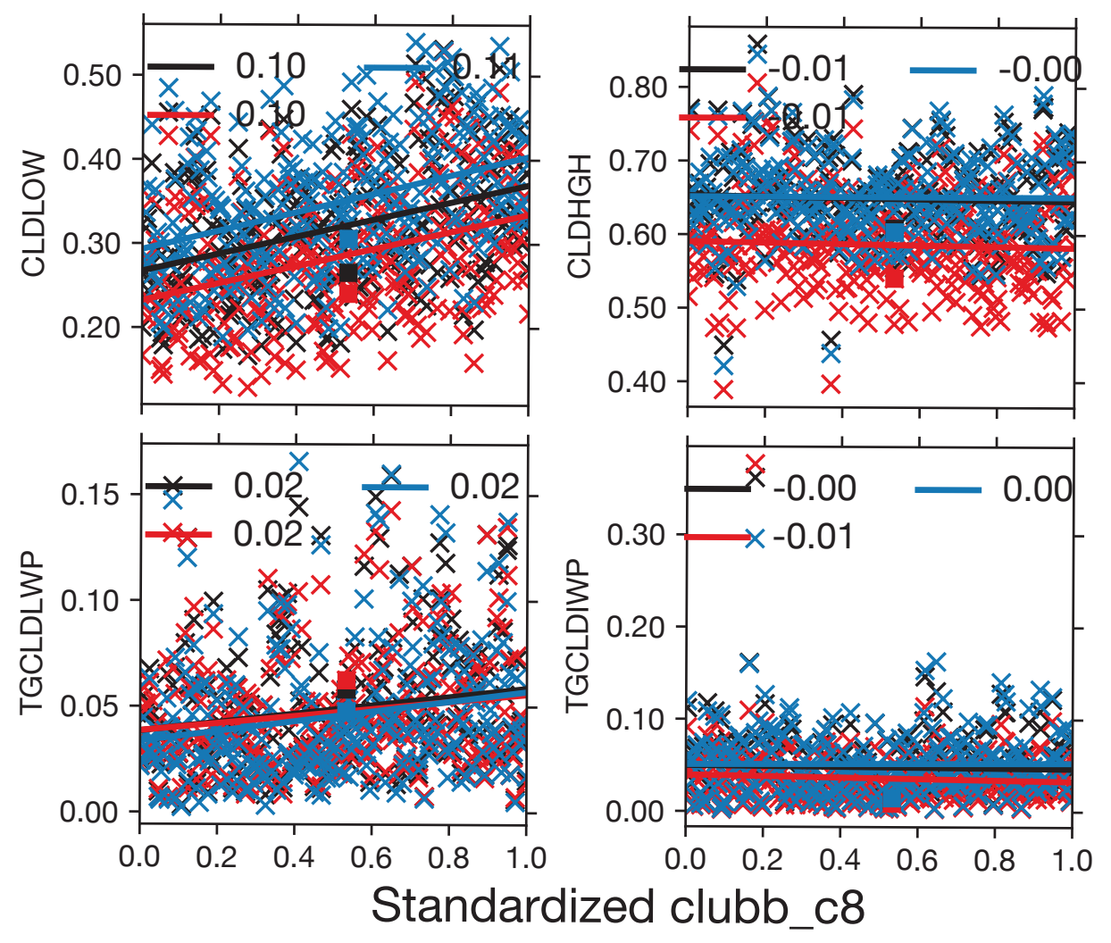


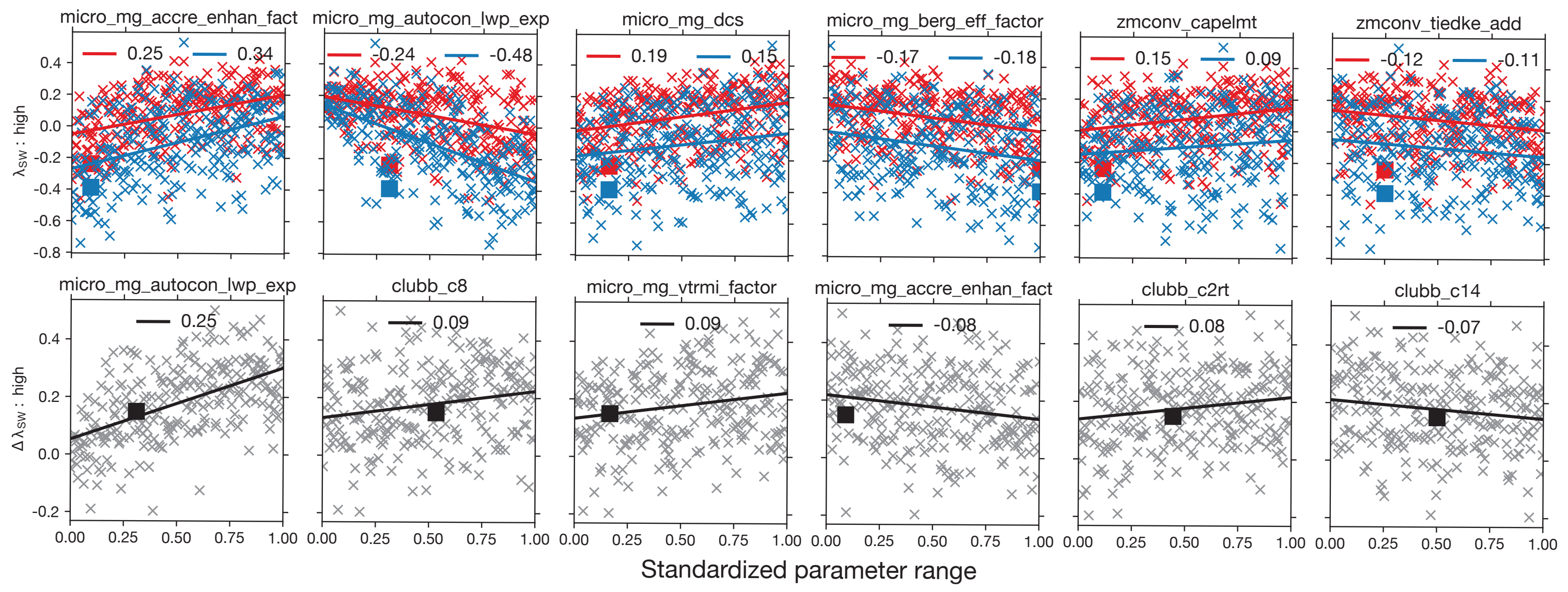
Results: continued



Over the low-lat. ascending regime, moist turbulence & deep convection have the strongest impact on the SW λ_{cld} nonlinearity

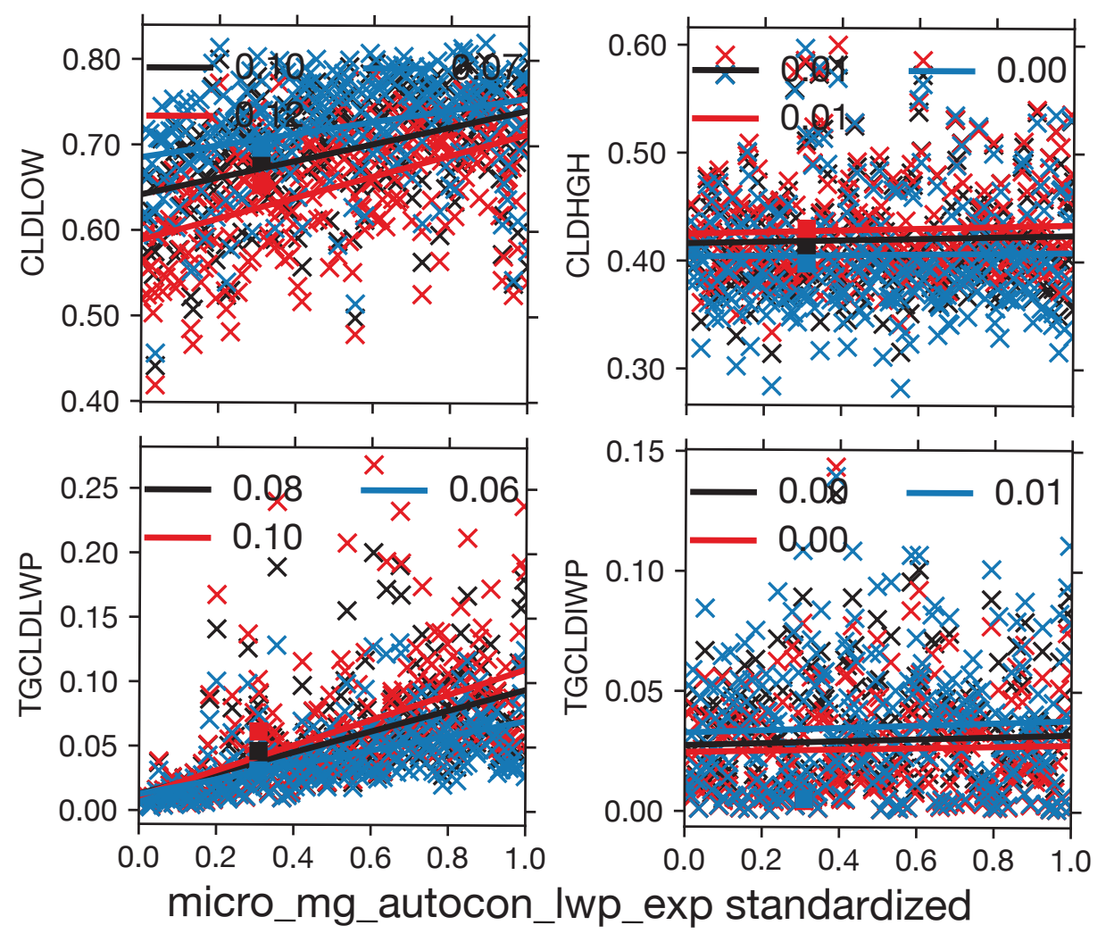
1. Temperature-dependent surface moisture flux change?





Over the high-lat. regime, cloud microphysics has the strongest impact on the SW λ_{cld} nonlinearity

1. Temperature-dependent adiabatic cloud water content change?
2. Temperature-dependent cloud ice content change?



4. Preliminary summary

- **Within the model parameter space, the cloud feedback exhibits strong and robust state dependence, i.e., asymmetrical response to warming/cooling**
- **Mechanisms are cloud regime specific, and may include the dependence of stratocumulus fraction, low-tropospheric stability, moisture flux/content, cloud ice content on the background temperature.**