Uncertainty in model climate sensitivity traced to representations of cumulus precipitation microphysics

Ming Zhao

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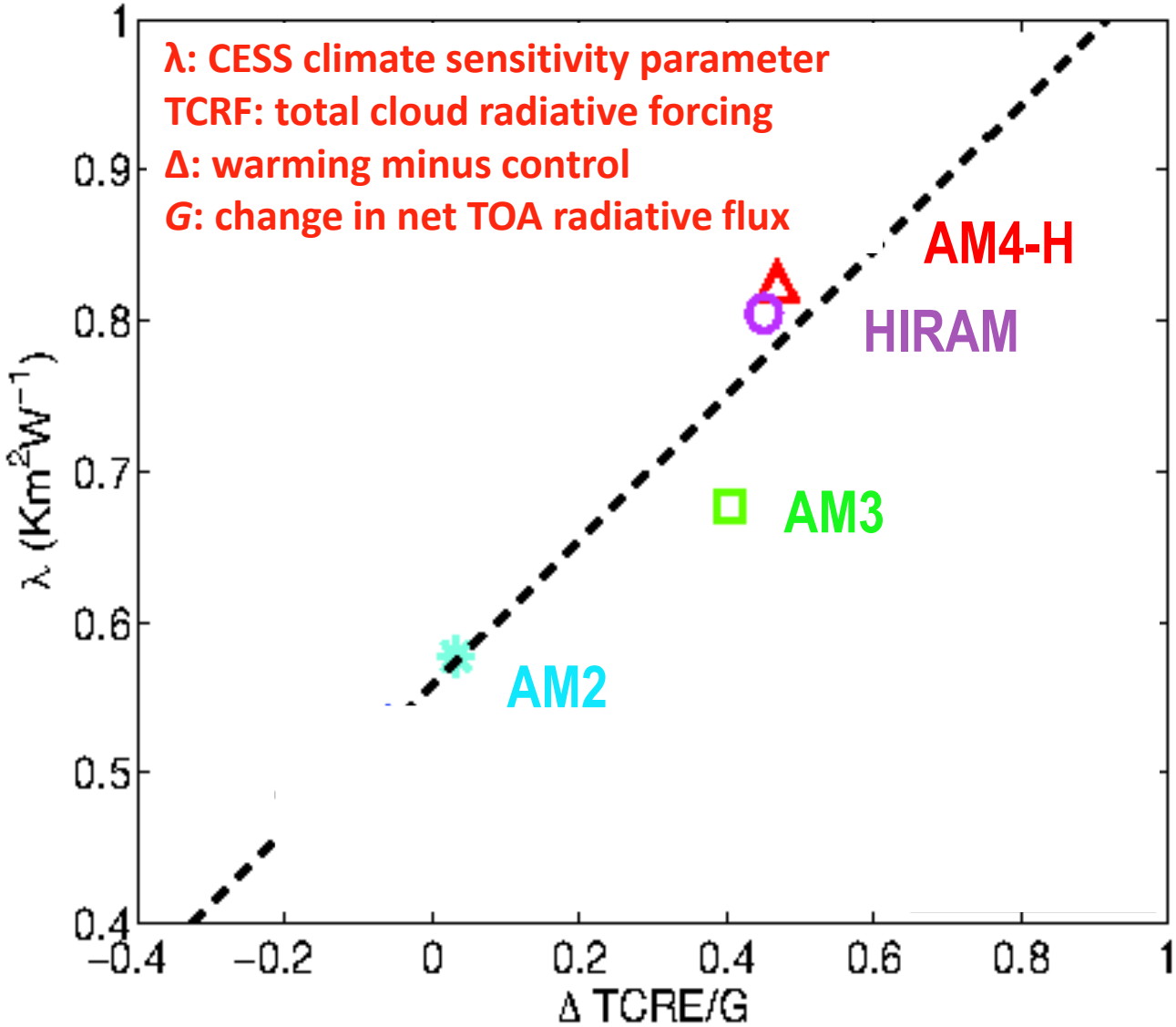
In collaboration with J-C Golaz, I.M. Held, V. Ramaswamy, S.-J. Lin, Y. Ming, P. Ginoux, B. Wyman, L.J. Donner, D. Paynter and H. Guo

Recent GFDL GCMs produce a wide range of estimate of the ECS based on the CESS equilibrium climate sensitivity parameter

AM3, HIRAM, AM4-H show marked increase in climate sensitivity compared to AM2.

Estimate of equilibrium climate sensitivity parameter using the CESS EXP (unified 2K warming) yields

λ:	$(\mathrm{Km}^2/\mathrm{W})$
AM2:	**0.58**
AM3:	**0.68**
HIRAM:	**0.80**
AM4-H:	**0.82**

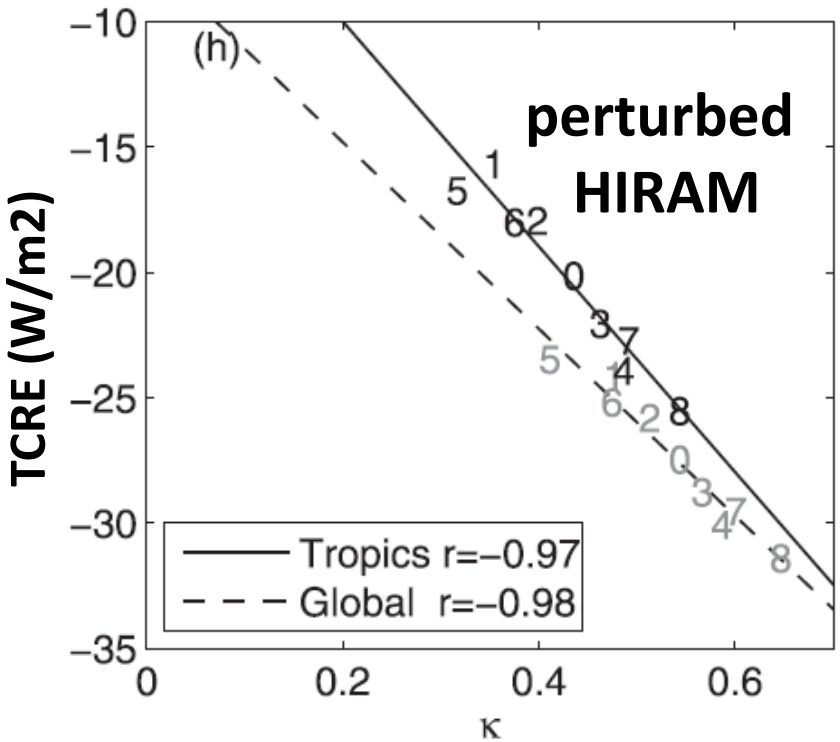


Cloud feedback parameter

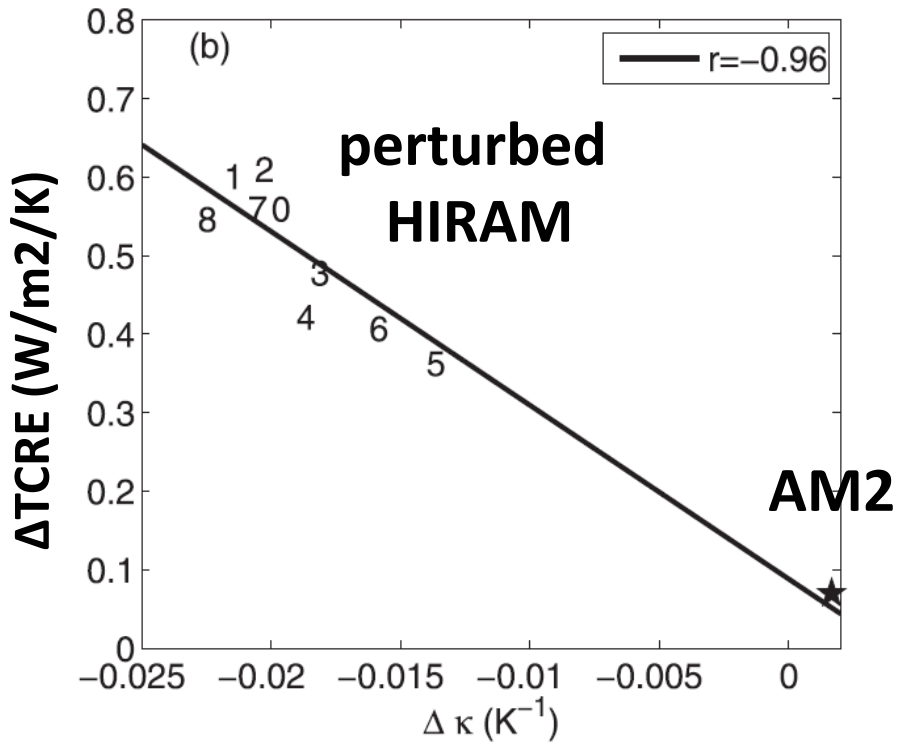
Convective detrainment efficiency may be a key in affecting GCM simulated clouds and cloud feedback

Convective detrainment efficiency (Zhao 2014, J. Climate)

$$\kappa_c = \frac{C_c - P_c}{P_c} = \frac{1}{e_c} - 1, \quad e_c = \frac{P_c}{C_c}, \quad \kappa_c = f(\text{mixing, microphysics,...})$$



Convective detrainment efficiency



Changes in detrainment efficiency

Can we create a low sensitivity AM4 with minimum changes to model formulation?

AM3, HIRAM, AM4-H show marked increase in climate sensitivity compared to AM2.

The equilibrium climate sensitivity parameter based on the CESS EXP (unified 2K warming) yield

λ:	$(\mathrm{Km}^2/\mathrm{W})$
AM2:	0.58
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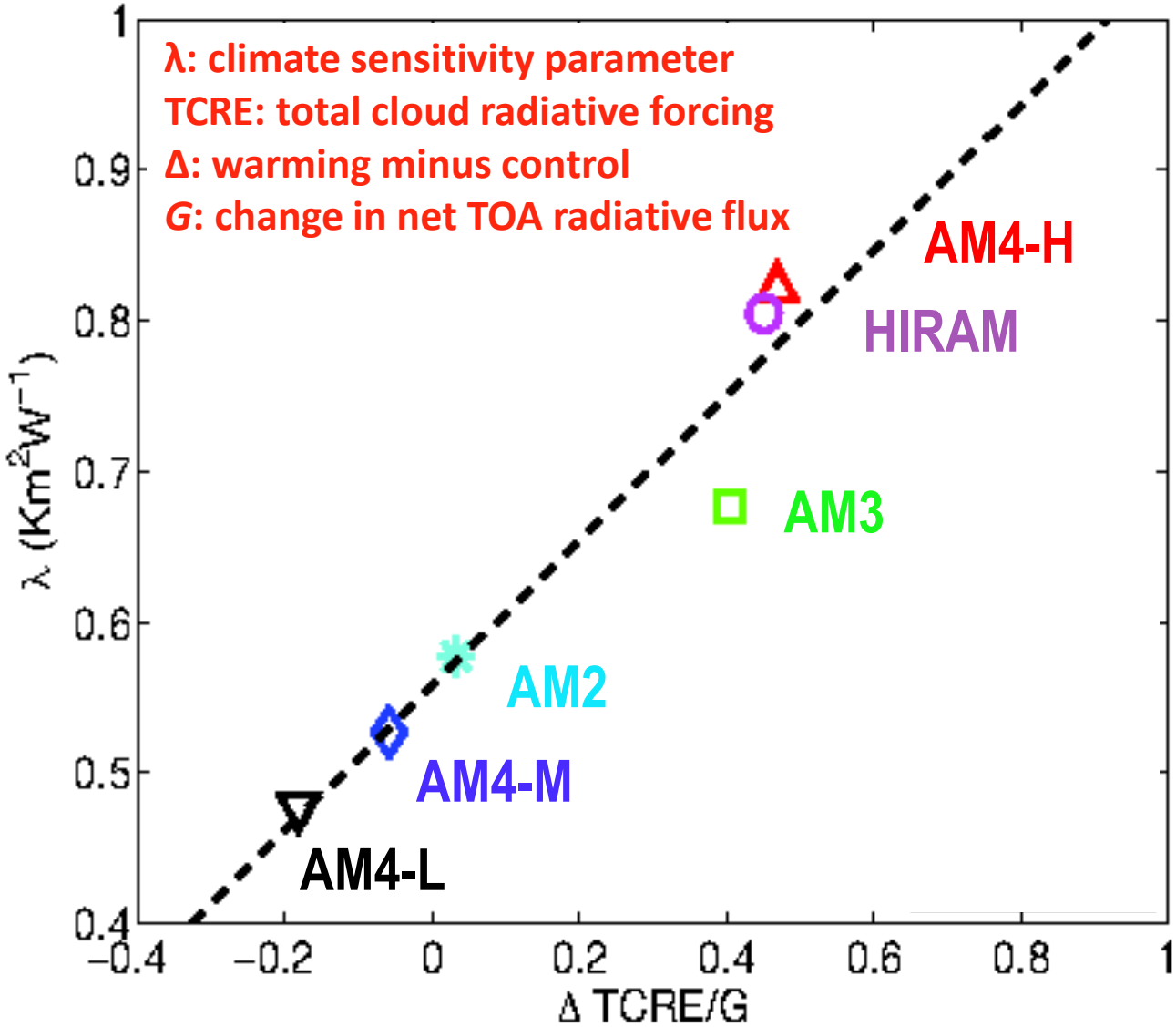
HIRAM:	0.80
AM4-H:	0.82
AM4-M:	0.54
AM4-L:	0.48



Cloud feedback parameter

Modifications in convective precipitation treatment

AM4-H uses modified UW convection scheme (Bretherton et. al 20014)

- **Threshold removal in AM4-H:** ***(Emanuel & Zivkovic-Rothman 1999)***

$$P = M_c \max(q_c - q_{c0}, 0), \qquad q_{c0} = \begin{cases} q_0 & T \geq 0°\mathrm{C} \\ q_0\left(1 - \dfrac{T}{T_{crit}}\right) & T_{crit} < T < 0°\mathrm{C} \\ 0 & T \leq T_{crit} \end{cases}$$

$Parameters$	H	M	L
q_0 (g/kg)	1.5	0.8	0.8
T_{crit} (°C)	-90	N/A	N/A
β_l (Pa^{-1})	N/A	1.5e-5	4.0e-5
β_i (Pa^{-1})	N/A	3.0e-5	8.5e-5
α	N/A	4	1

- **Fractional removal in AM4-M, AM4-L:**

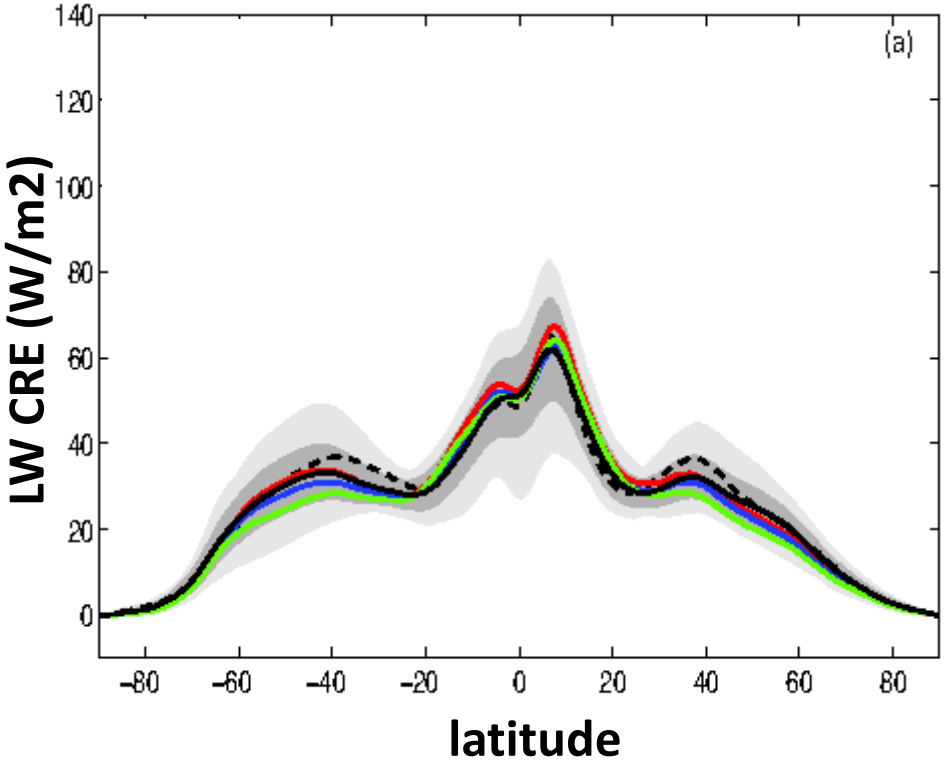
$$P = M_c(\beta \Delta p)\max(q_c - q_{c0}, 0), \quad \beta(T) = \begin{cases} \beta_l, & q_{c0} = q_0,\ T \geq -5°\mathrm{C} \\ \beta_l + \dfrac{-5-T}{-5+25}(\beta_i - \beta_l), & q_{c0} = 0,\ -25°\mathrm{C} < T < -5°\mathrm{C} \\ \beta_i, & q_{c0} = 0,\ T \leq -25°\mathrm{C} \end{cases}, \ \beta \text{ in unit}: \mathrm{Pa}^{-1}$$

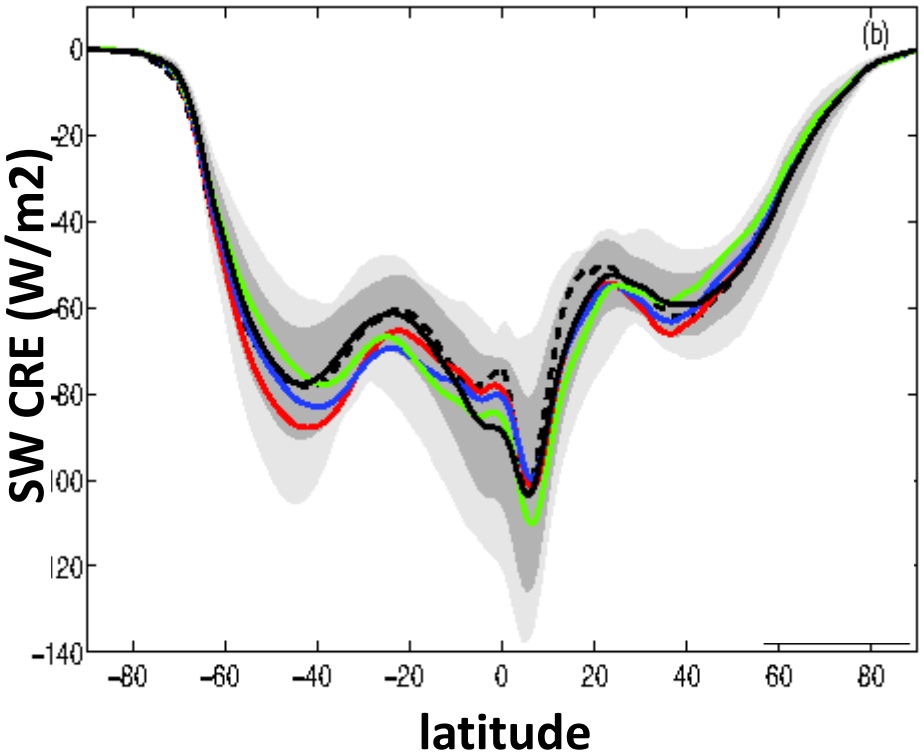
$$\beta_{deep} = \alpha \beta_{shallow}$$

- **Fractional removal in AM2 RAS:** ***(GFDL GAMDT 2004)***

$$P = M_c \beta q_c, \qquad \beta(p_T) = \begin{cases} 0.975, & p_T \leq 500\mathrm{hPa} \\ 0.5 + \dfrac{800 - p_T}{800 - 500}(0.975 - 0.5), & 800\mathrm{hPa} < p_T < 500\mathrm{hPa} \\ 0.5, & p_T \geq 800\mathrm{hPa} \end{cases}$$

Comparison of simulated LW and SW cloud radiative effect with the CMIP5 ensemble and the CERES observational estimate





Red: AM4-H **black:** CMIP5 mean **dashed: CERES**

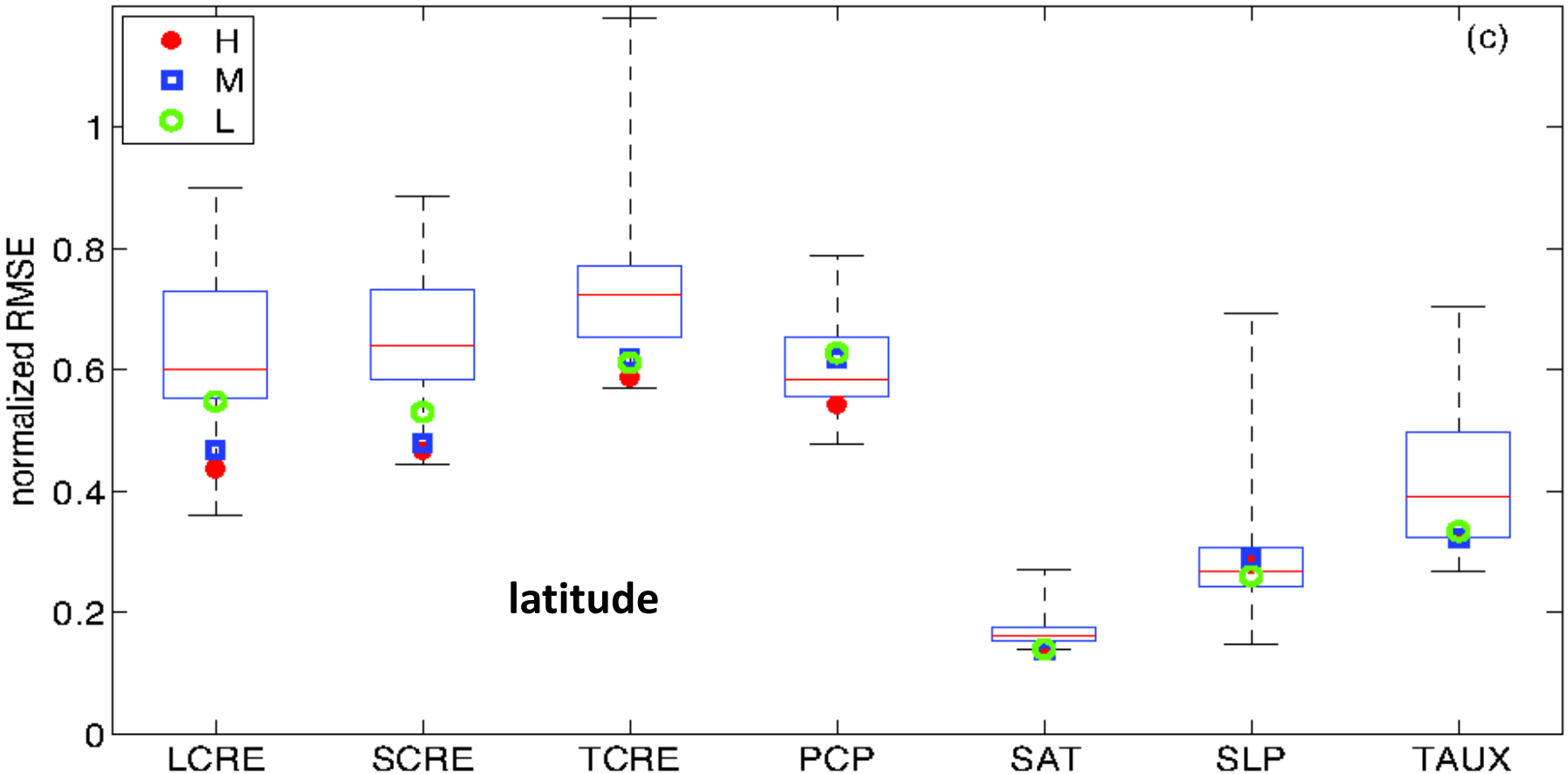
Blue: AM4-M **light shading: CMIP5 1-std**

Green: AM4-L **dark shading: CMIP5 min/max**

Comparison of the normalized RMSE of selected fields with CMIP5 ensemble (CREs: CRERES; PCP: GPCPv2; SAT, SLP, TAUX: ERA-INTERIM)

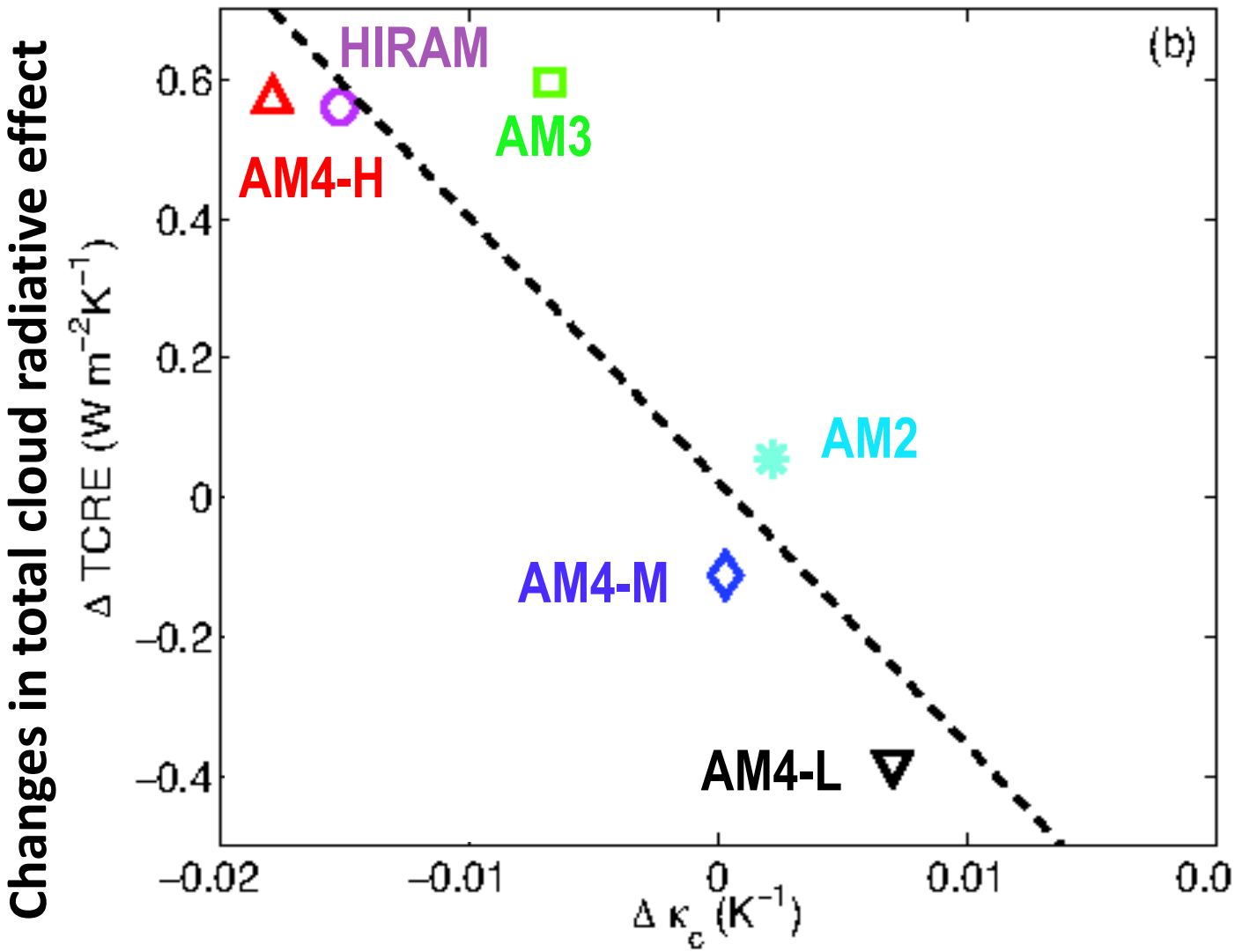
Red: AM4-H
Blue: AM4-M
Green: AM4-L

boxplot: CMIP ensemble
red line: median; blue edge: 25th and 75th
whiskers: CMIP5 min/max



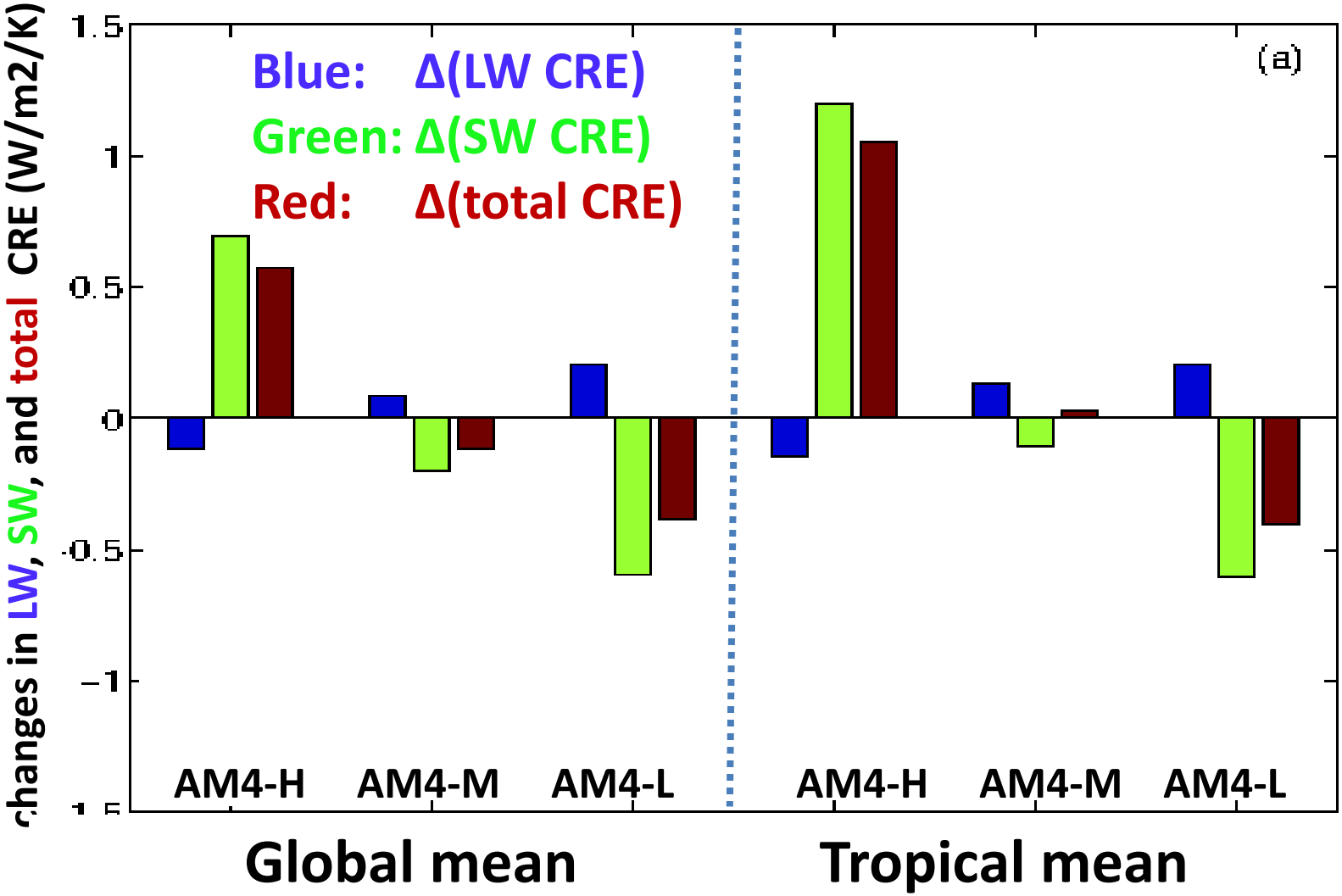
LCRE: LW CRE, SCRE: SW CRE, TCRE: total CRE, PCP: precipitation,
SAT: surface air temperature, SLP: sea-level-pressure, TAUX: zonal wind stress

AM4- M&L produce large reductions in total CRE, which may be explained by changes in convective detrainment efficiency

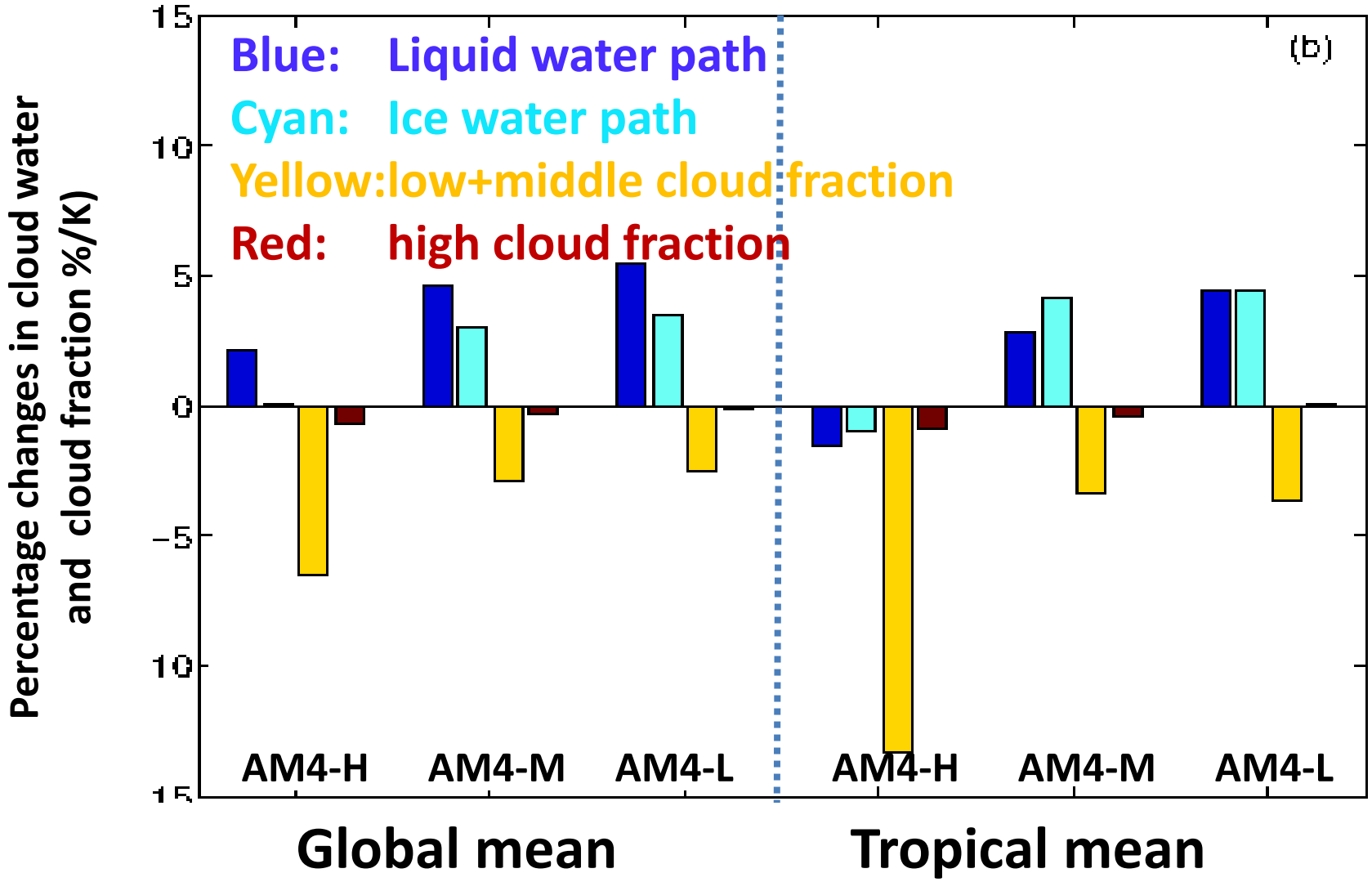


Changes in convective detrainment efficiency

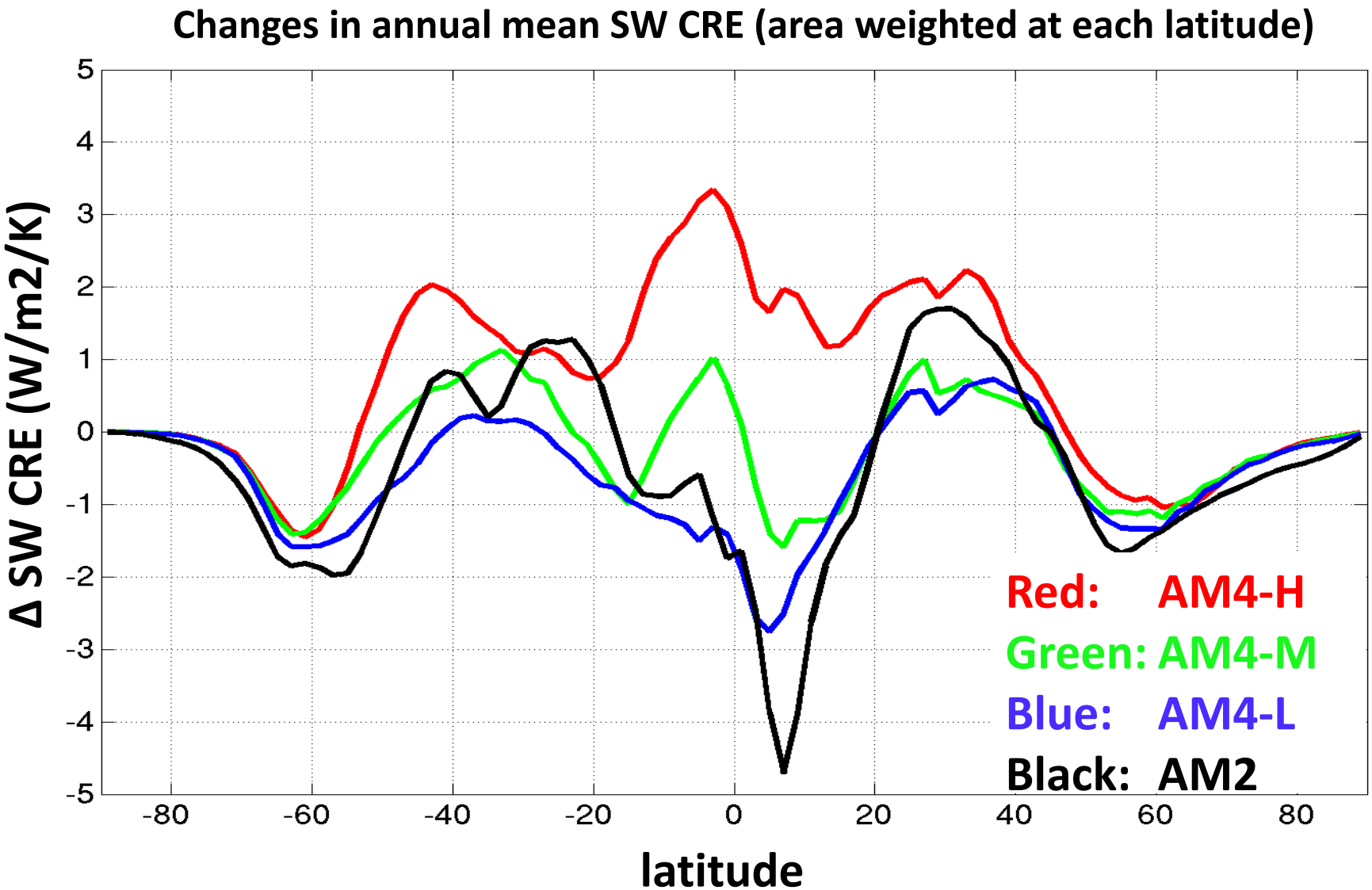
Changes in total CRE are dominated by tropical SW CRE



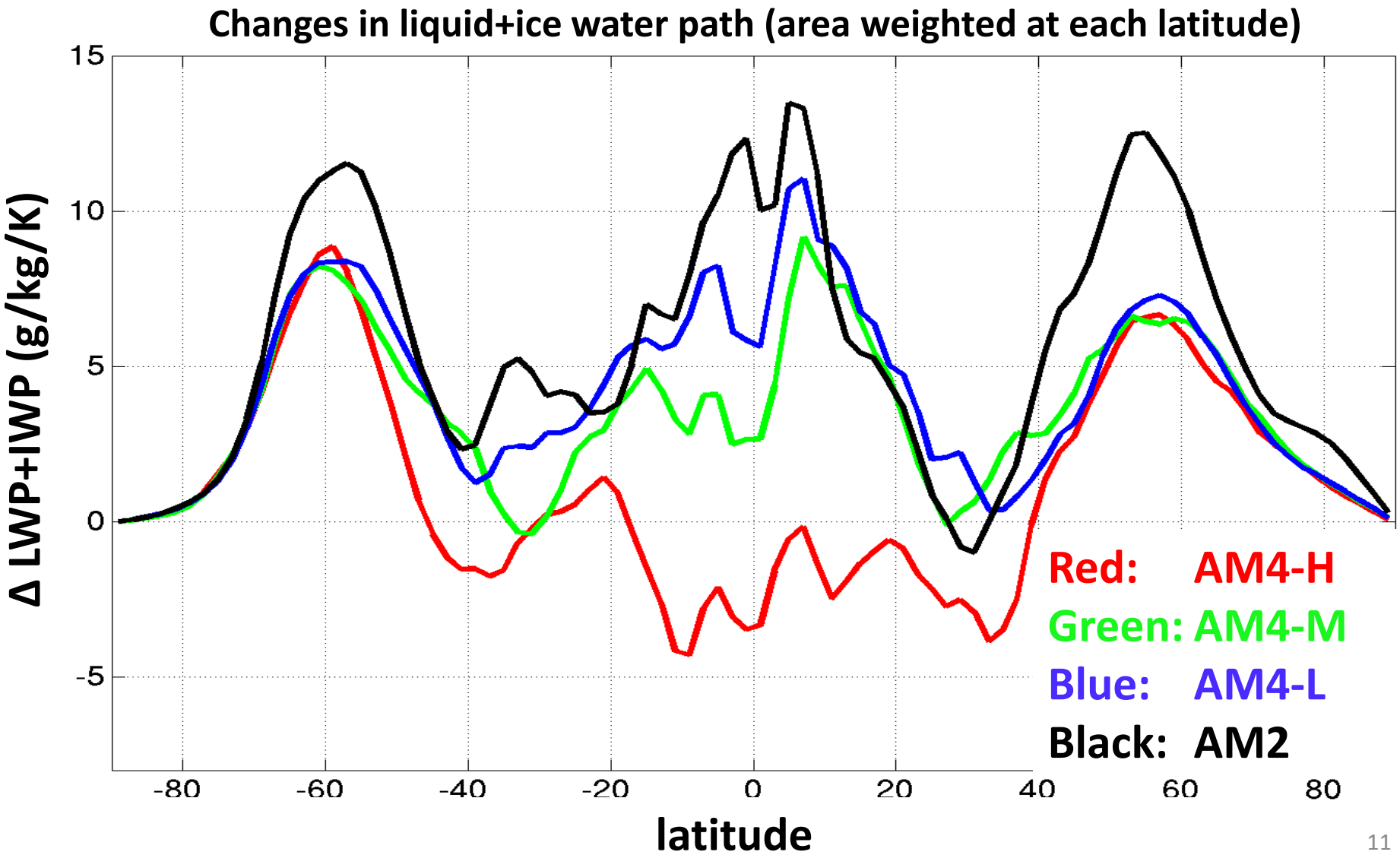
Changes in cloud responses are dominated by tropical low+middle cloud fraction and liquid+ice water path



Latitudinal distribution of changes in SW CRE
(changes in AM4-M &AM4-L are more like AM2 than AM4-H)

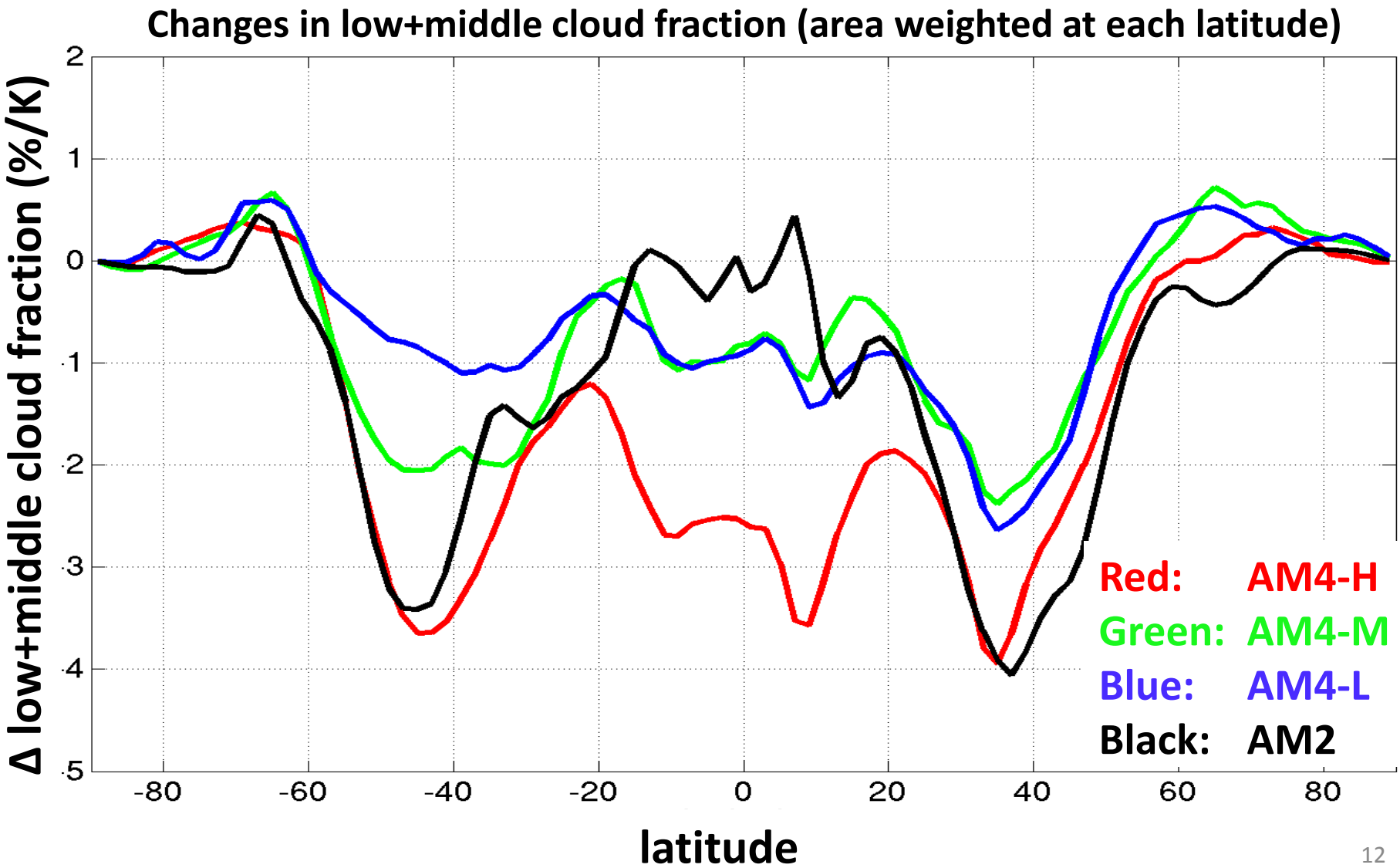


Latitudinal distribution of changes in IWP+IWP
(changes in AM4-M &AM4-L are more like AM2 than AM4-H)

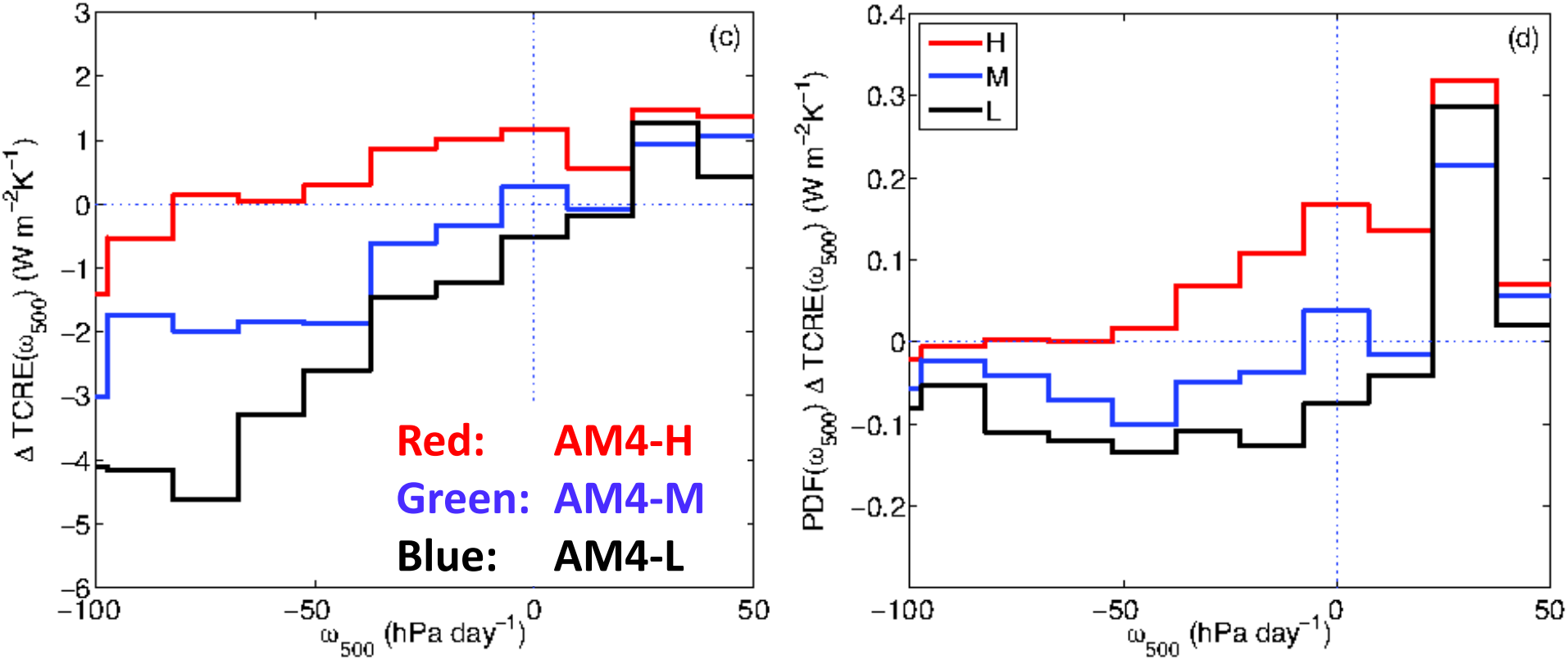


Latitudinal distribution of changes in low+mid cloud fraction

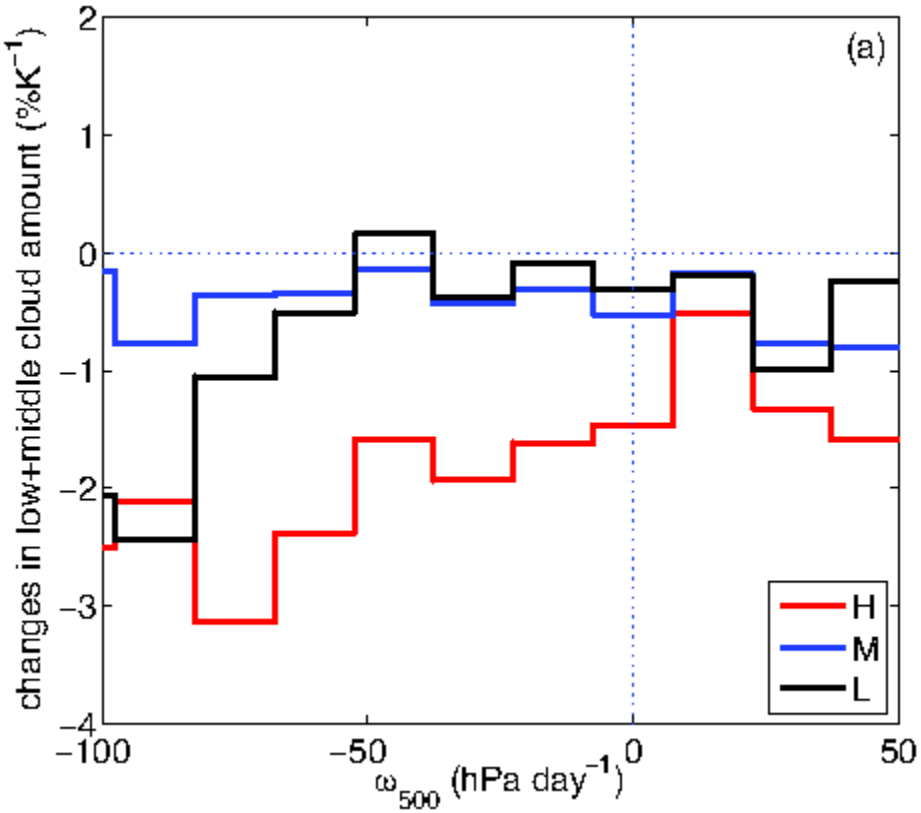
(changes in AM4-M &AM4-L are more like AM2 than AM4-H)

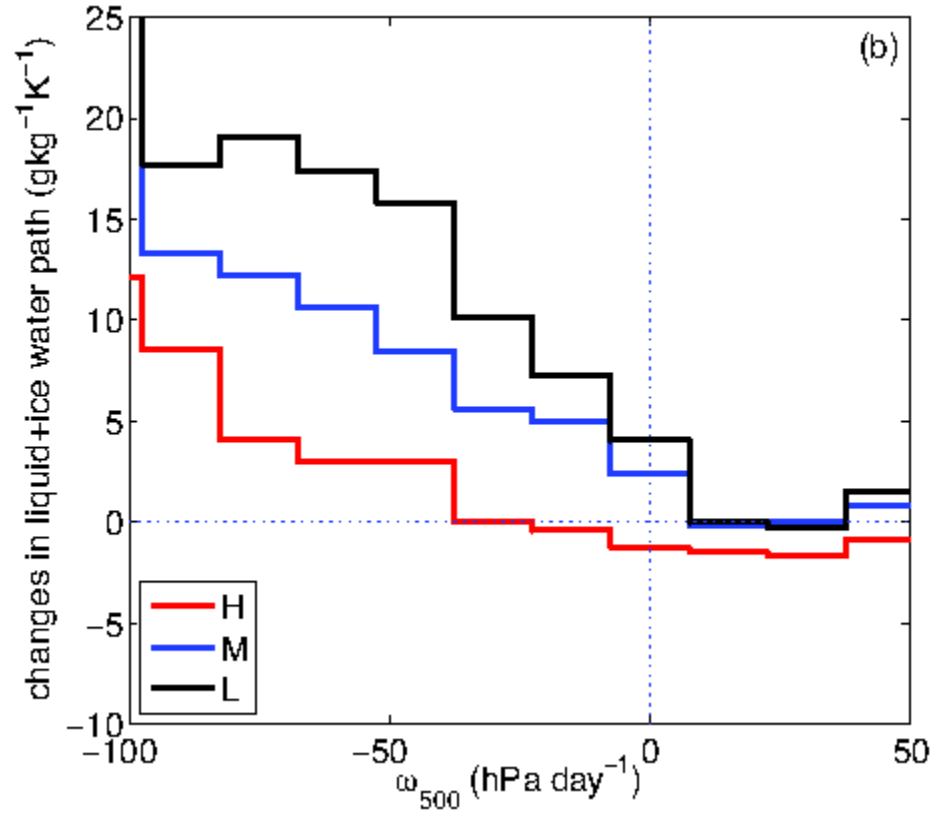


Changes in total CRE partitioned into different large-scale regimes characterized by ω500



Changes in tropical low+middle cloud fraction and LWP+IWP partitioned into different large-scale regimes characterized by ω500



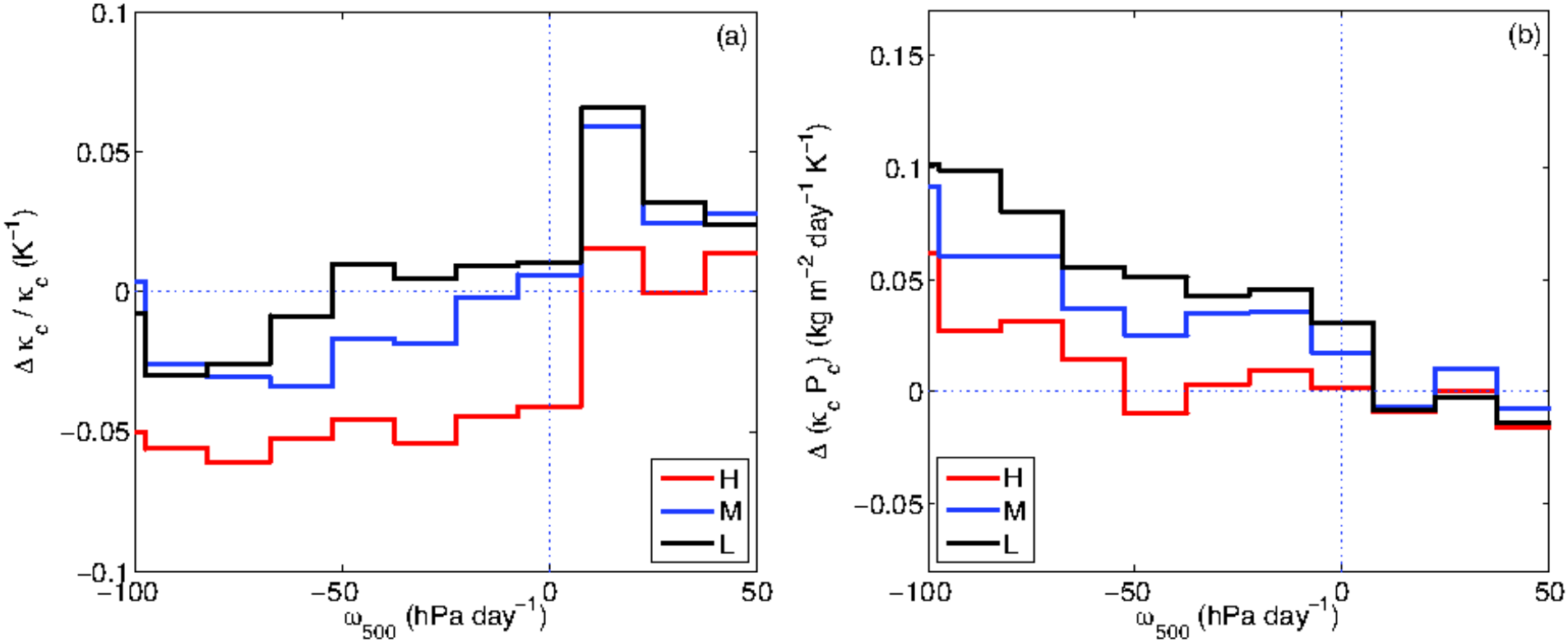


Red: AM4-H

Green: AM4-M

Blue: AM4-L

Changes in convective detrainment efficiency partitioned into different large-scale regimes characterized by ω500



Red: AM4-H

Green: AM4-M

Blue: AM4-L

Summary

- Cloud feedback and climate sensitivity can be strongly affected by model parameterization of convective precipitation. The effect comes through both ascent and decent regions, and may be understood through bulk convective detrainment efficiency.

- Compared to the threshold remover scheme in AM4-H, the fractional remover and associated treatment in mixed and ice-phase clouds in AM4 M&L tend to produce much reduced positive (or negative) cloud feedback.

- Given the uncertainty in parameterizing convective precipitation microphysics, the result suggests that one can engineer climate sensitivity. Explicitly constructed low & high sensitivity models may be useful for studying historical climate variability and future projections.

End

Changes in convective detrainment partitioned into different large-scale regimes characterized by ω500