Using a Multi-Physics Ensemble for Exploring Diversity in Cloud-Shortwave Feedback in GCMs

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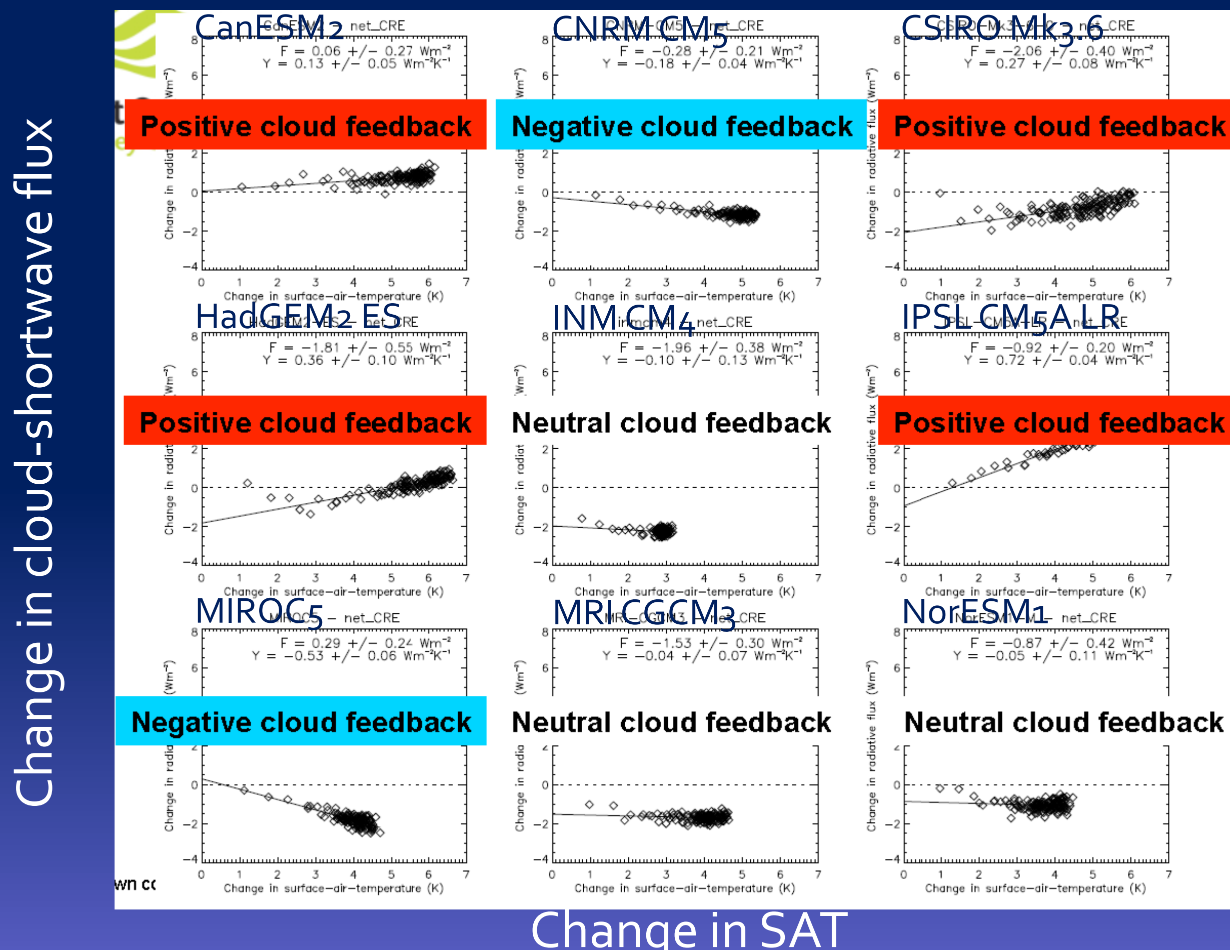
Did climate sensitivity get converged in CMIP5 ?

Equilibrium climate sensitivity (ECS) to 2xCO_2 in CMIP models

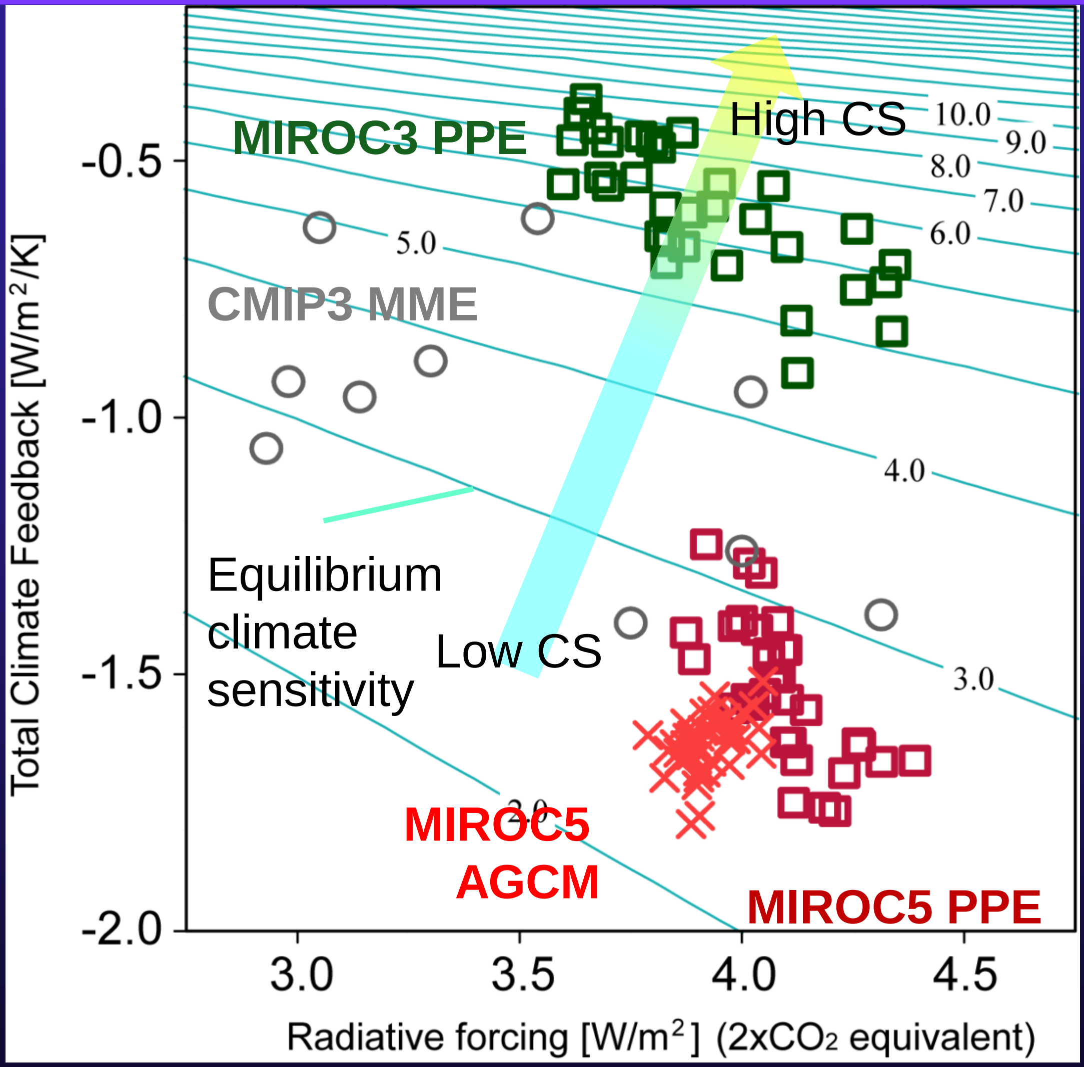
IPCC report	FAR	SAR	TAR	AR4	AR5
climate sensitivity	1.5-4.5K	1.0-3.5K	1.5-4.5K	2.1-4.4K	2-4.6K *as of Oct2011

Mitchell et al. (1990), Kattenberg et al. (1996), Cubasch et al. (2001), IPCC (2007)



Courtesy of K Taylor

Filling the gap between two PPEs



MIROC5 Multi-Physics Ensemble (MPE)

Replacing one or more schemes in MIROC5 w/ old ones:

- ✓ Std (=MIROC5)
- ✓ (old)CLD
- ✓ (old)CNV
- ✓ (old)VDF
- ✓ (old)CLD+CNV
- ✓ (old)CNV+VDF
- ✓ (old)CLD+VDF
- ✓ (old)CLD+CNV+VDF ~ MIROC3

- ✓ Structural difference > Parametric difference
- ✓ Any strategy to link them ?

Watanabe et al. (2012, JC)

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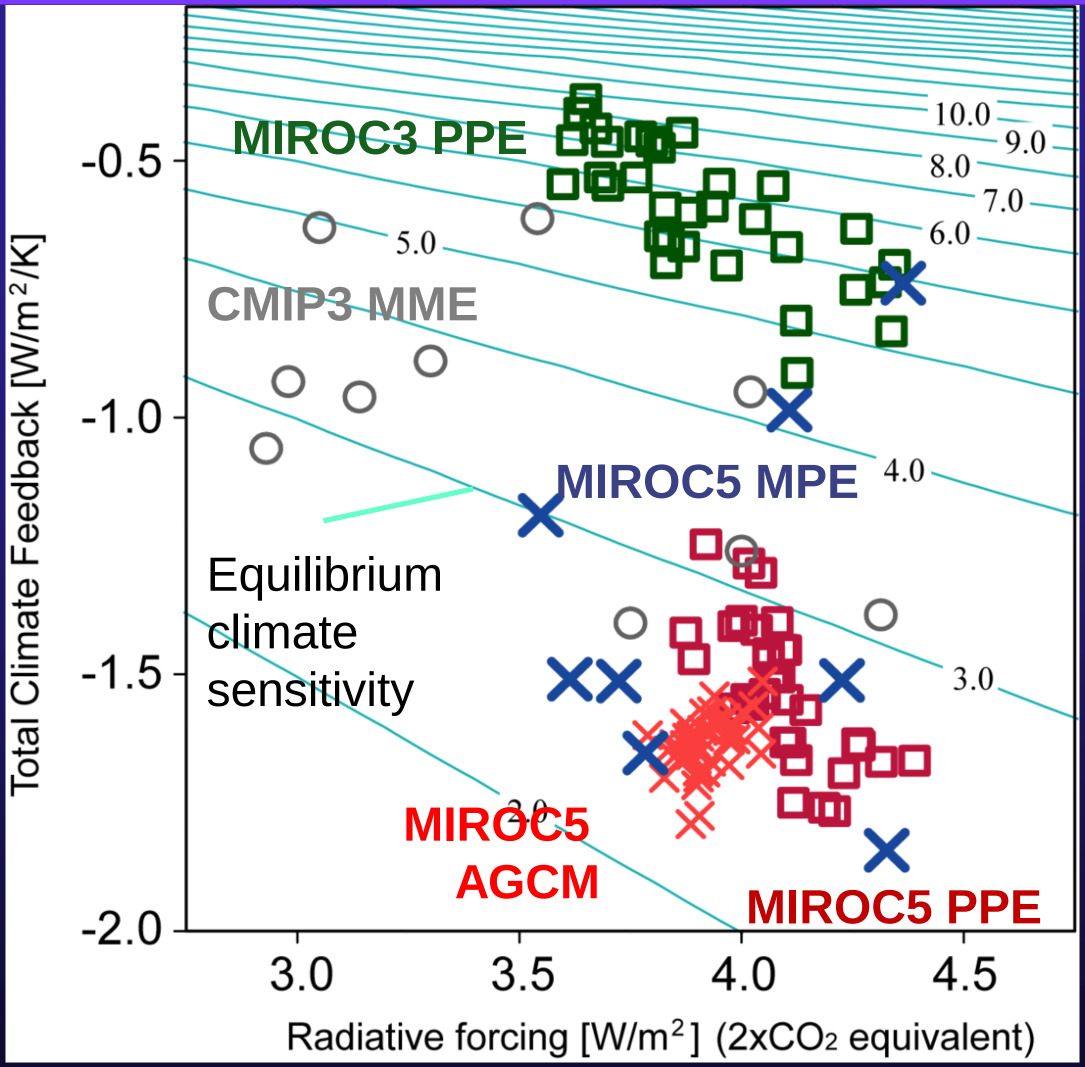

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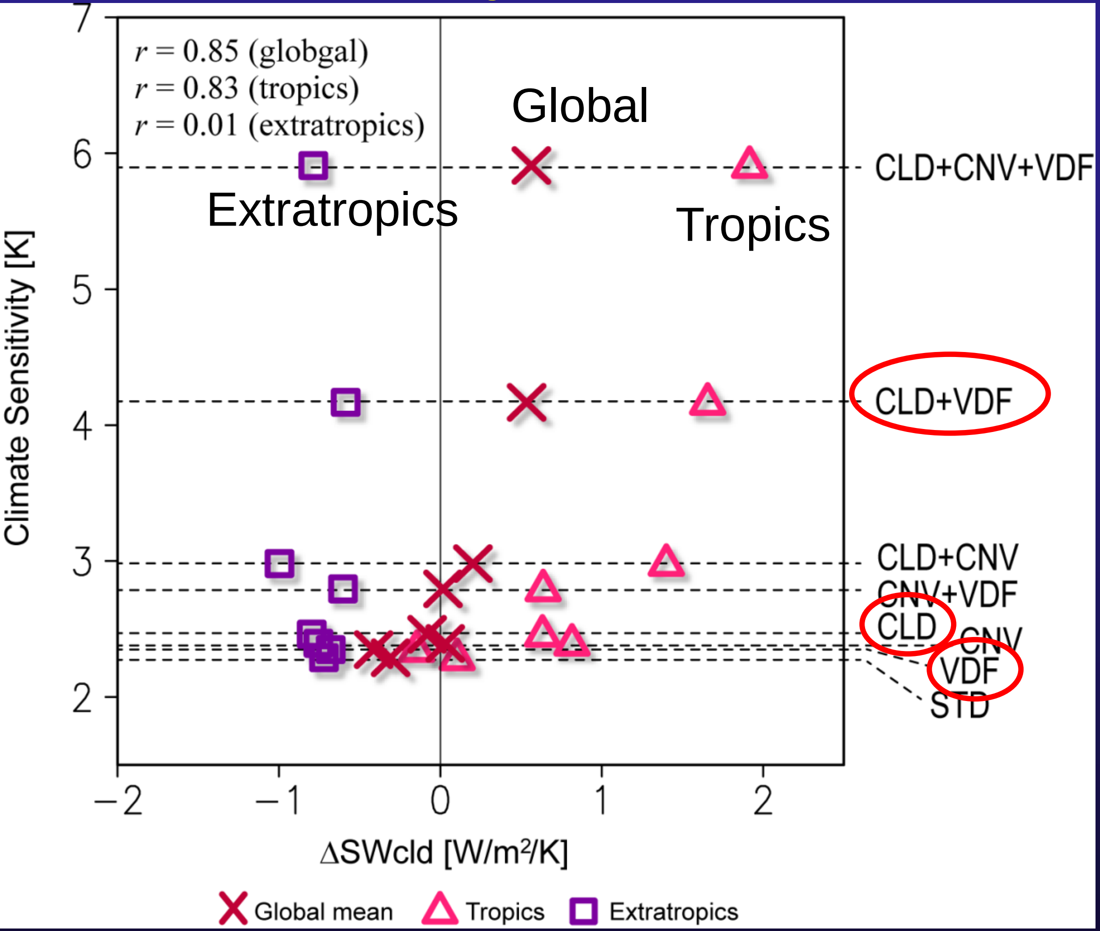
Coupling processes making differences

MIROC MPE:
For each of 8 models,
✓ 6y CTL
✓ 6y 4xCO_2
✓ 6y +SST (from CGCM)
runs are performed w/ AGCM
After slight re-tuning

Climate sensitivity vs SWcld feedback



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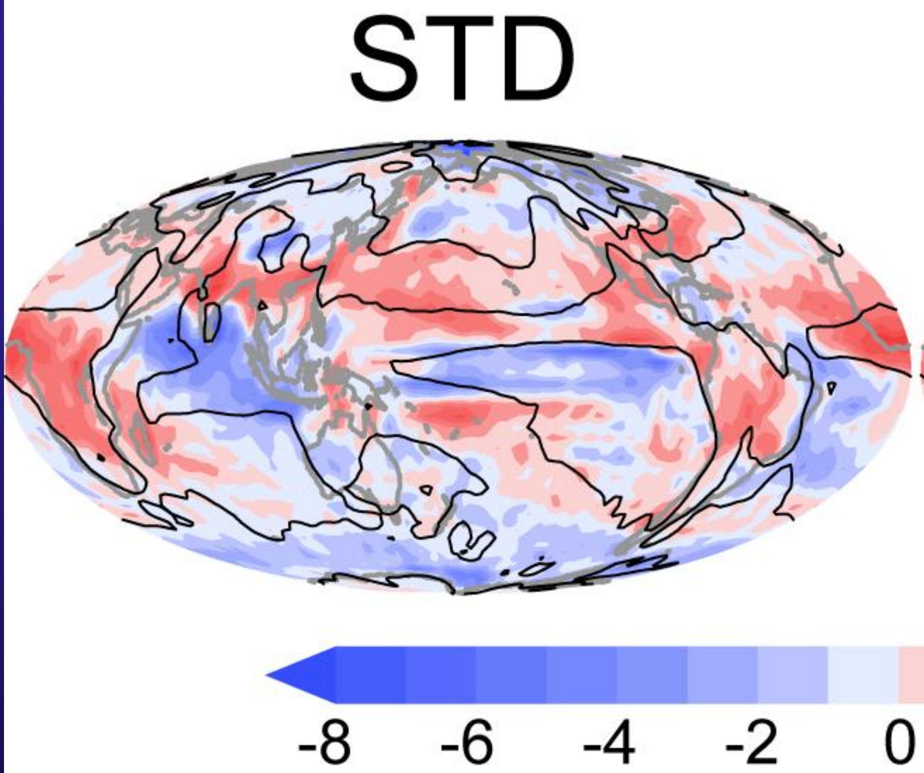
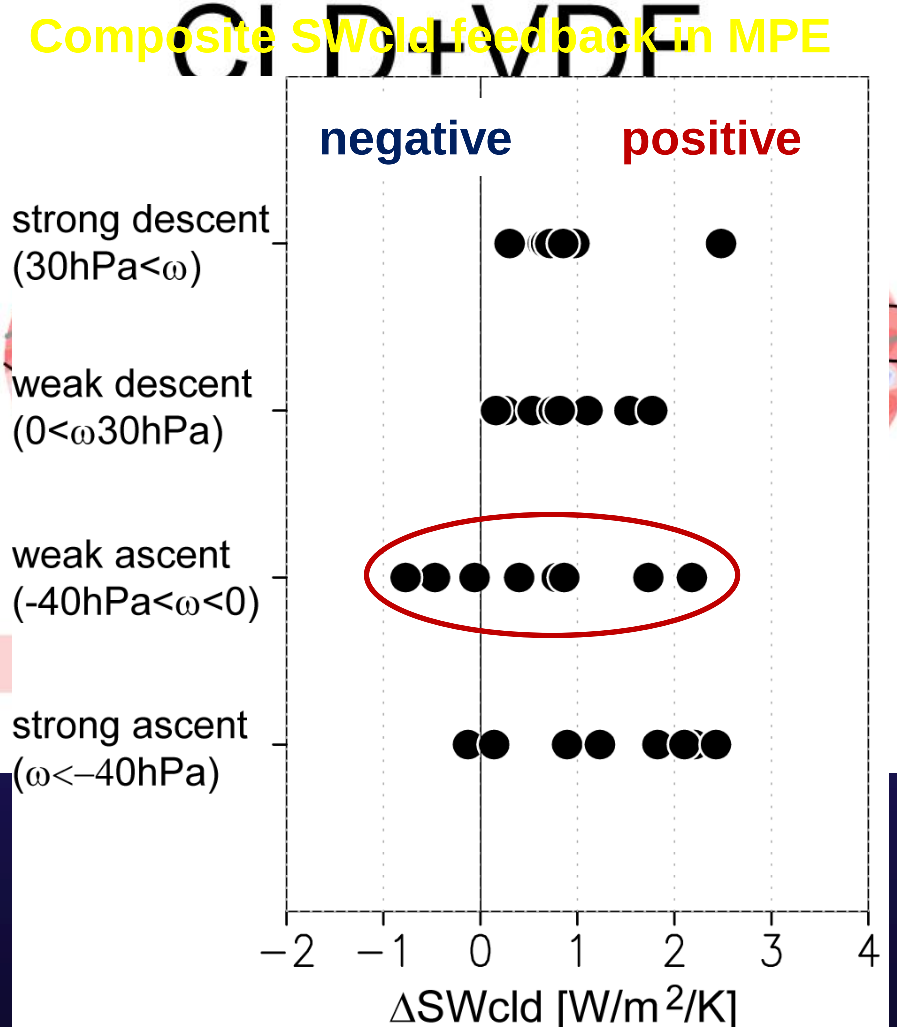
Processes are nonlinear, e.g.,

CLD -> Small impact
VDF -> Small impact
CLD+VDF -> Large impact !!

'Feedback occurs thru the interaction of a suite of parameterized processes rather than from any single process' (Zhang & Bretherton 2008)

SWcld feedback patterns



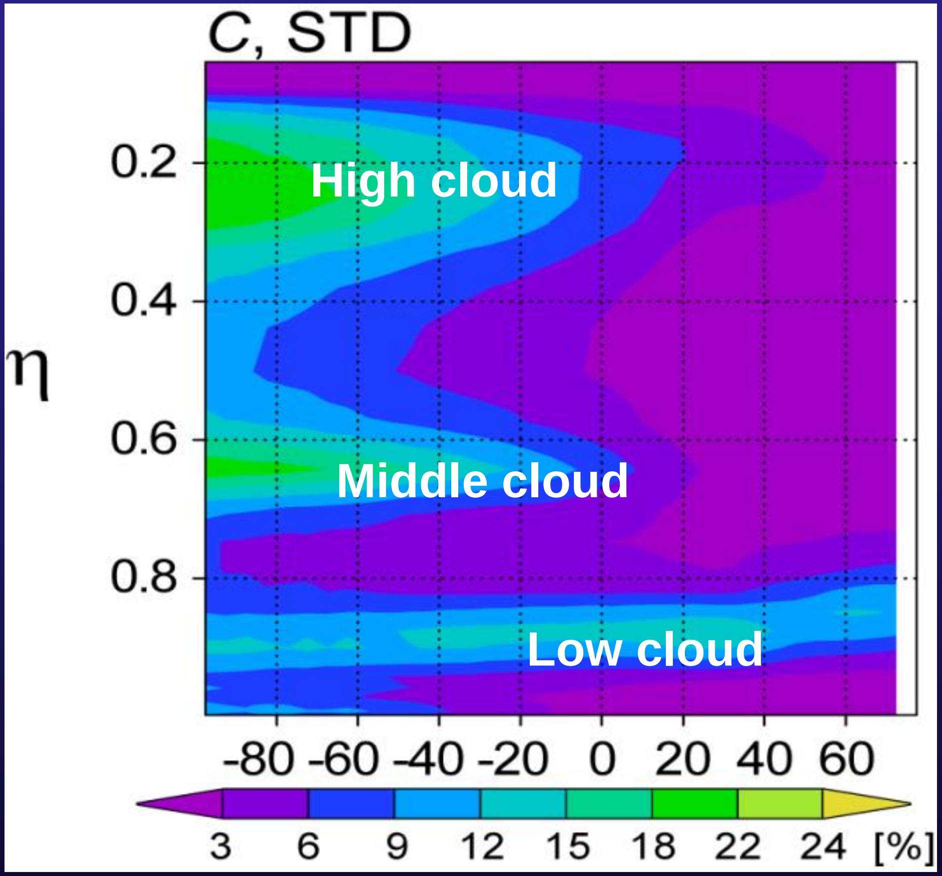


Watanabe et al. (2012)

- ✓ Robust positive feedback for the tropical subsidence regimes (at least in MIROC3/5)
- ✓ Large difference for the weak convective regime

→ Trade cumulus response?

Cloud regimes



Altitude (model's hybrid coordinate)

Circulation regime sorted by ω

Cloud diagnosis

Cloud fraction is a function of grid-scale saturation excess, Qc, and PDF moments, μ_i:

$$C = f\left(Q_c, \mu_i\right)$$

$$\boxed{Q_c = a_L \left\{q_t - q_s(T_l, p)\right\}}$$

$$a_L = \left(1 + L\alpha_L / c_p\right)^{-1}$$

$$\alpha_L = \partial q_s / \partial T\big|_{T=T_l}$$

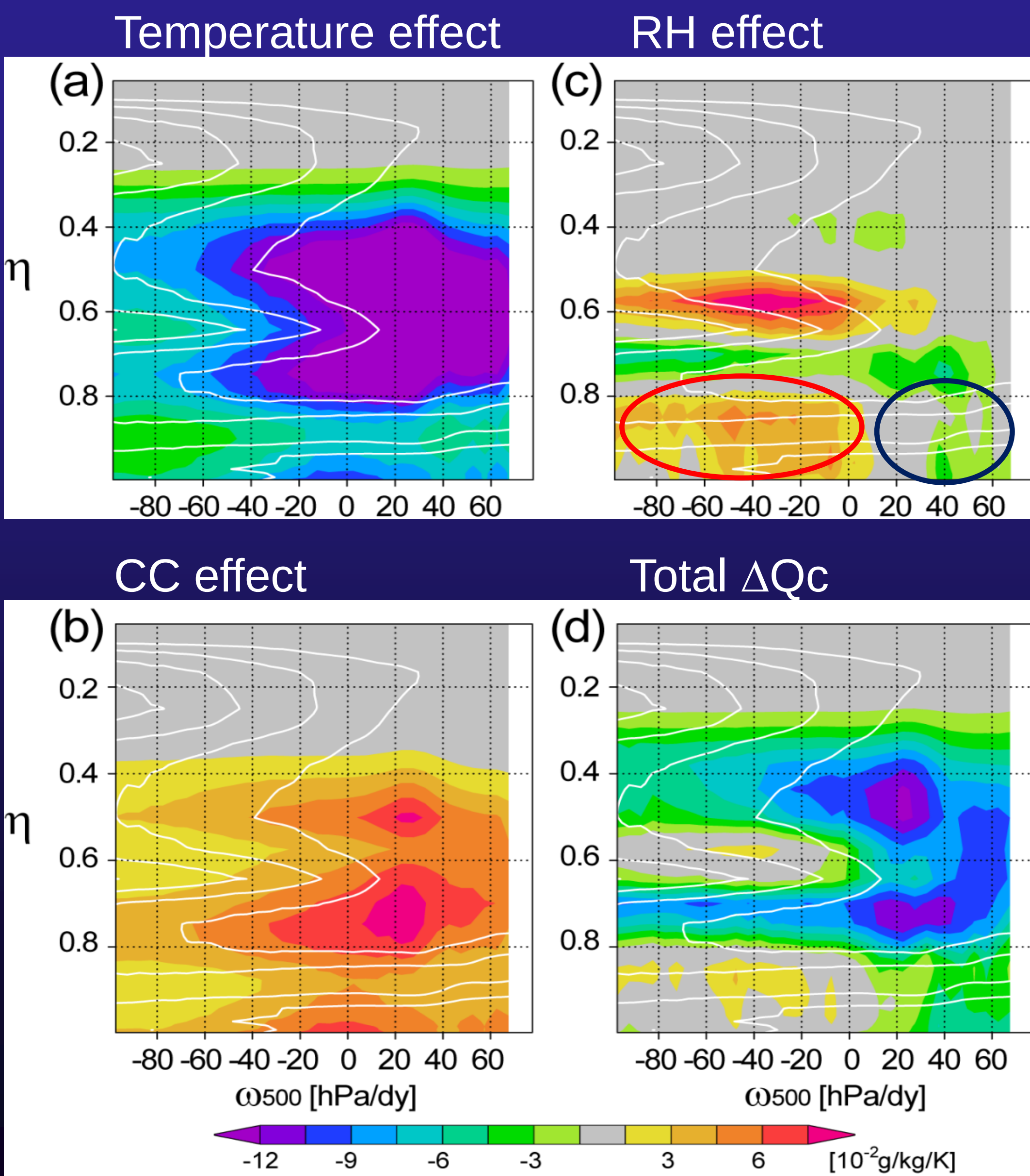
Change in +SST run (Δ) can be decomposed into 4 terms (overbar is the mean value in CTL)

$$\Delta Q_c = \bar{a}_L\left(\Delta q_t - \Delta q_s\right) + \Delta a_L\left(\bar{q}_t - \bar{q}_s\right)$$

$$= \bar{a}_L\Big[\underbrace{(\bar{H}-1)\bar{\alpha}_L \Delta T}_{\text{Temperature effect}} + \underbrace{\Delta H \bar{q}_s}_{\text{RH effect}} + \underbrace{\left\{1-(\bar{H}-1)\bar{\alpha}_L L c_p^{-1}\right\}\Delta q_l}_{\text{Condensate effect}}\Big] + \underbrace{\Delta a_L\left(\bar{q}_t - \bar{q}_s\right)}_{\text{CC effect}}$$

Sources of Qc change

STD



In the middle troposphere of the convective regime, temp. effect (-) cancels the CC effect (+), with the net being weakly negative

In the low level, positive RH effect due to slight increase in RH (~2%) is crucial

$$\Delta H \approx \left(\Delta q \bar{q}_s - \bar{q} \Delta q_s \right) / \bar{q}_s^{\,2}$$

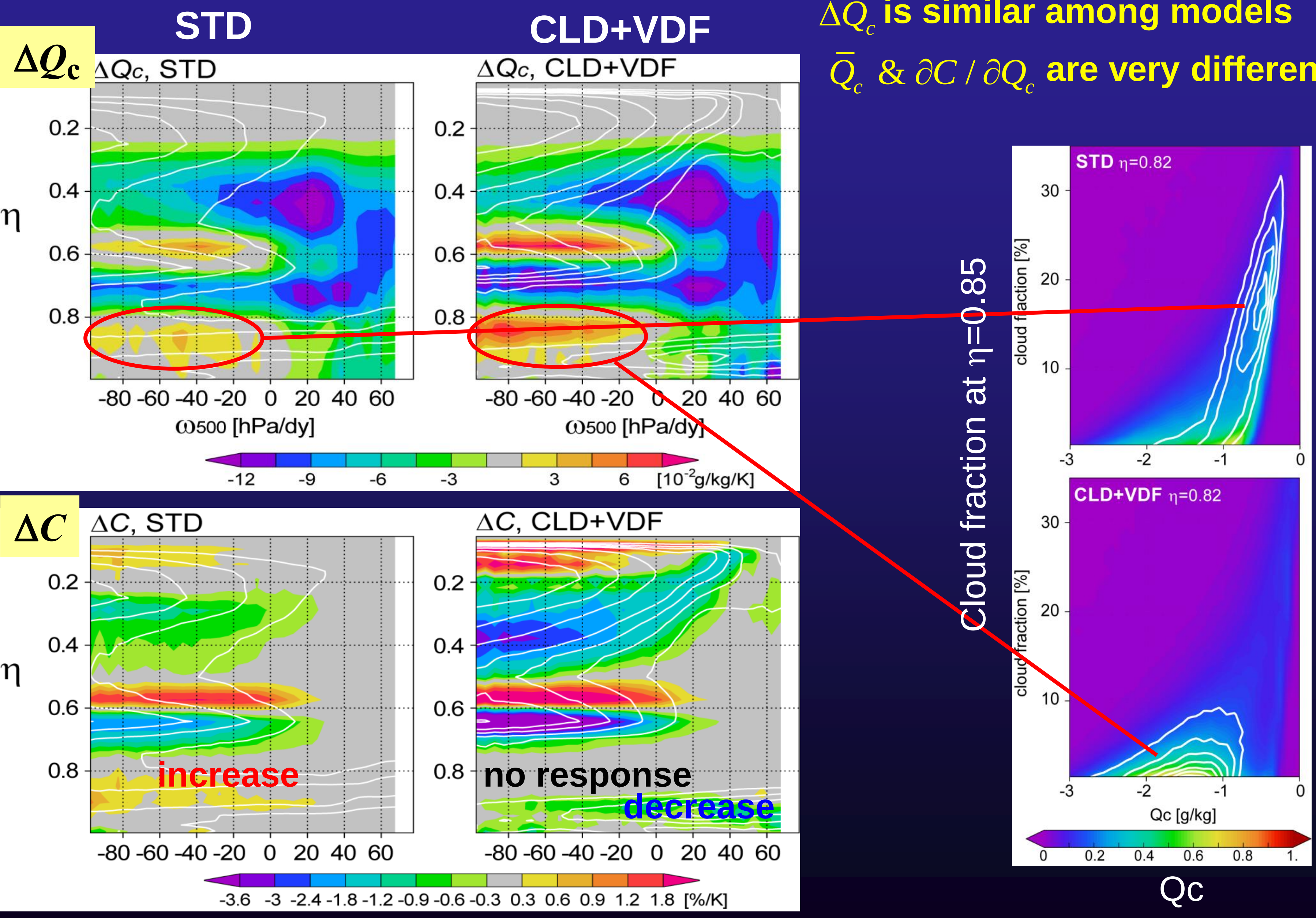
Positive ΔH comes from positive Δq, which is attributed to more active turbulence transport at $\eta > 0.8$

Negative ΔH is due to positive Δq_s, which results from a drying by larger ΔT than the effect of enhanced transport of q

Cloud regimes

ΔQ_c is similar among models

$\bar{Q}_c$ & $\partial C / \partial Q_c$ are very different



Summary

- ✓ Given *two* base models showing different cloud feedbacks, MPE can be a useful approach to understand sources of the different behaviour
- ✓ In MIROC MPE, no single process controls ΔSW_{cld}, but the coupling of two processes does:
  - ✓ cloud and turbulence schemes
  - ✓ convection and cloud schemes
- ✓ Change in the saturation excess has a similar structure among the models, but difference in the mean and sensitivity may cause an opposite response of low clouds