Modeling activity of the MIROC group for climate feedback and sensitivity studies

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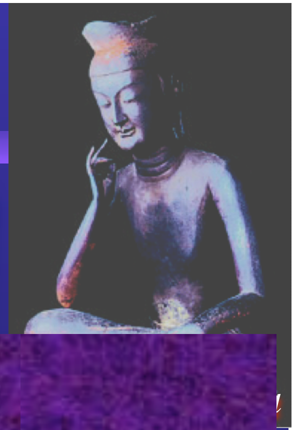
Background & Outline



Modeling activity by MIROC group

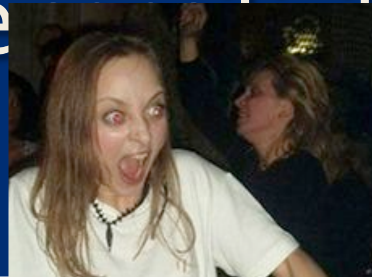
- ✓ Watanabe et al. 2010 JC (MIROC5)
- ✓ Yokohata et al. 2010 JC (MIROC3 PPE)
- ✓ Shiogama et al. 2011 CD (MIROC5 PPE) *
- ✓ Watanabe et al. 2011 ASL (MIROC5 20C)
- ✓ Watanabe et al. 2011 CD (MIROC3/5) #
- ✓ Watanabe et al. 2011 JC (MPE) *
- ✓ Yoshimori et al. 2011 JC (MIROC3 PPE) #
- ✓ Yokohata et al 2011 CD (MIROC3 PPE/MME) #

* submitted, # in press

Outline of this talk

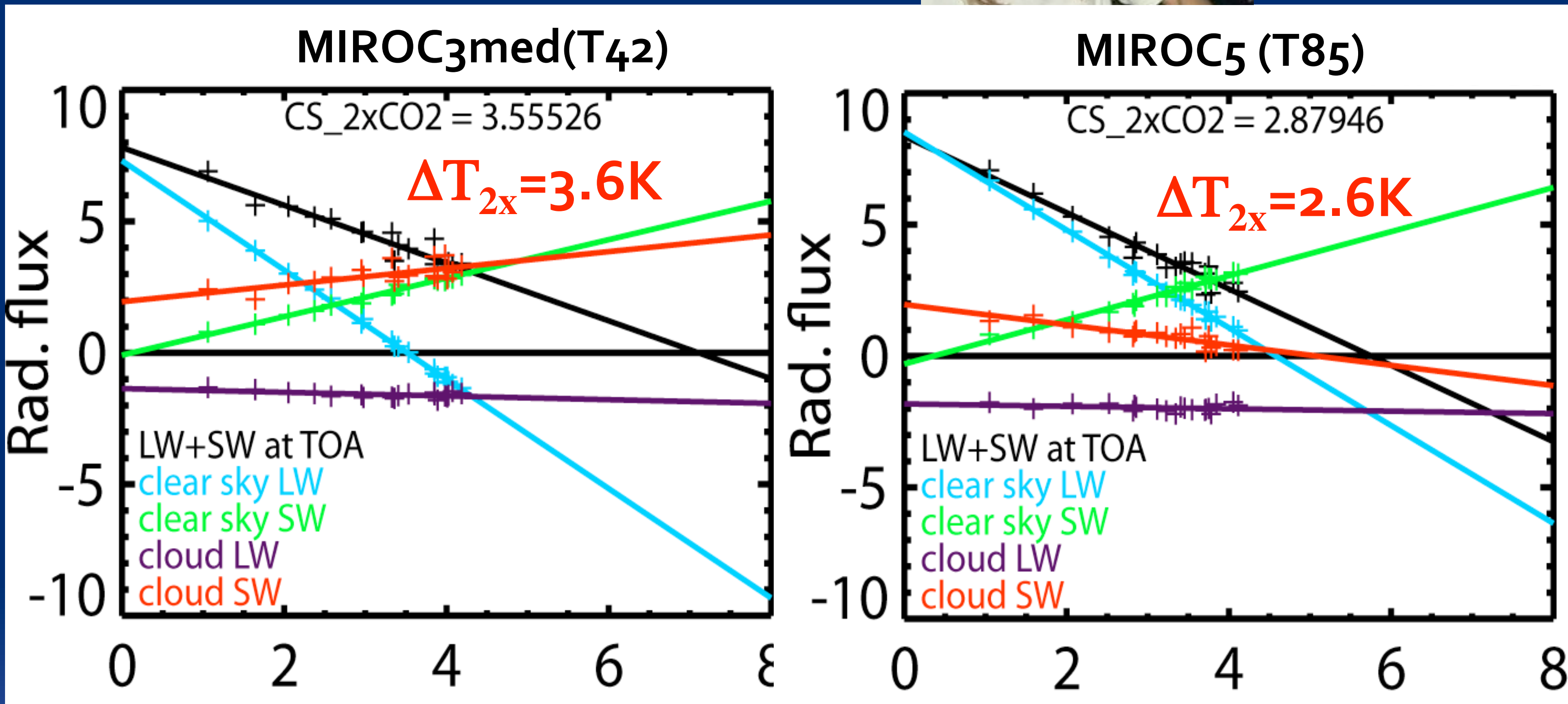
- ☐ Cloud feedbacks in MIROC3.2/MIROC5/CMIP3 MME
- ☐ Various ensembles using MIROCs

Equilibrium climate ty



$N = F -$

Gregory plots for 4xCO2



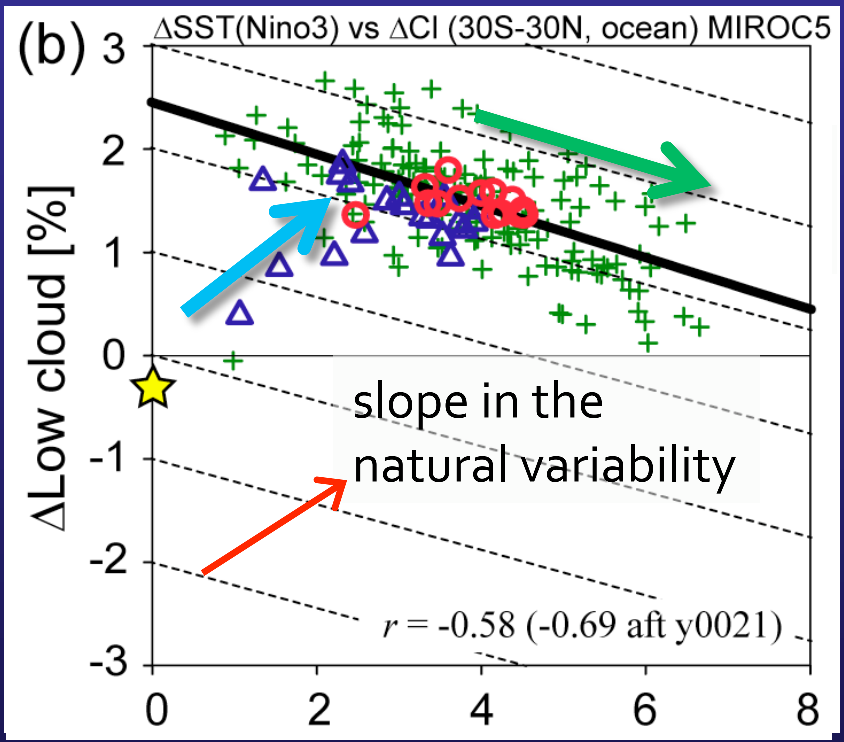
ΔSAT ΔSAT

Watanabe et al. (2010, JC)

- MIROC3 was a 'high-sensitivity model' in CMIP3
- Cloud-shortwave (SWcld) feedback is the key component

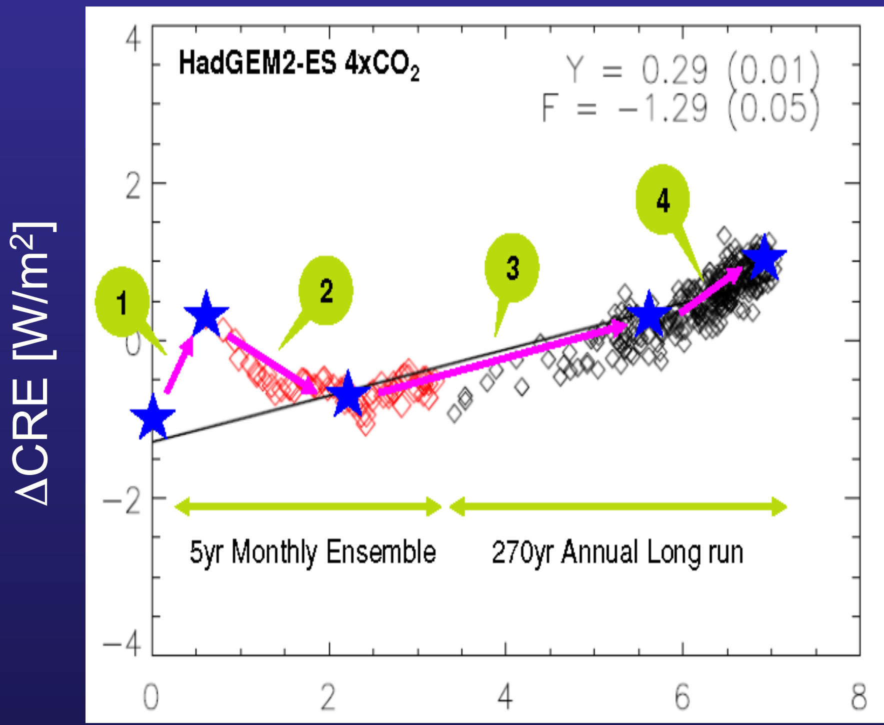
Multiple timescales of the cloud feedback

MIROC5 4xCO2 150y



Watanabe et al. (2011, Clim. Dyn.)

HadGEM2-ES 4xCO2



Courtesy of Tim Andrews

+ ann. mean, single run (150y)
○ decadal mean, single run
△ ann. mean, ensemble avg (20y)
★ initial month of △

Sign of the SWcld feedback is determined by the fast response of clouds during a few years in MIROCs

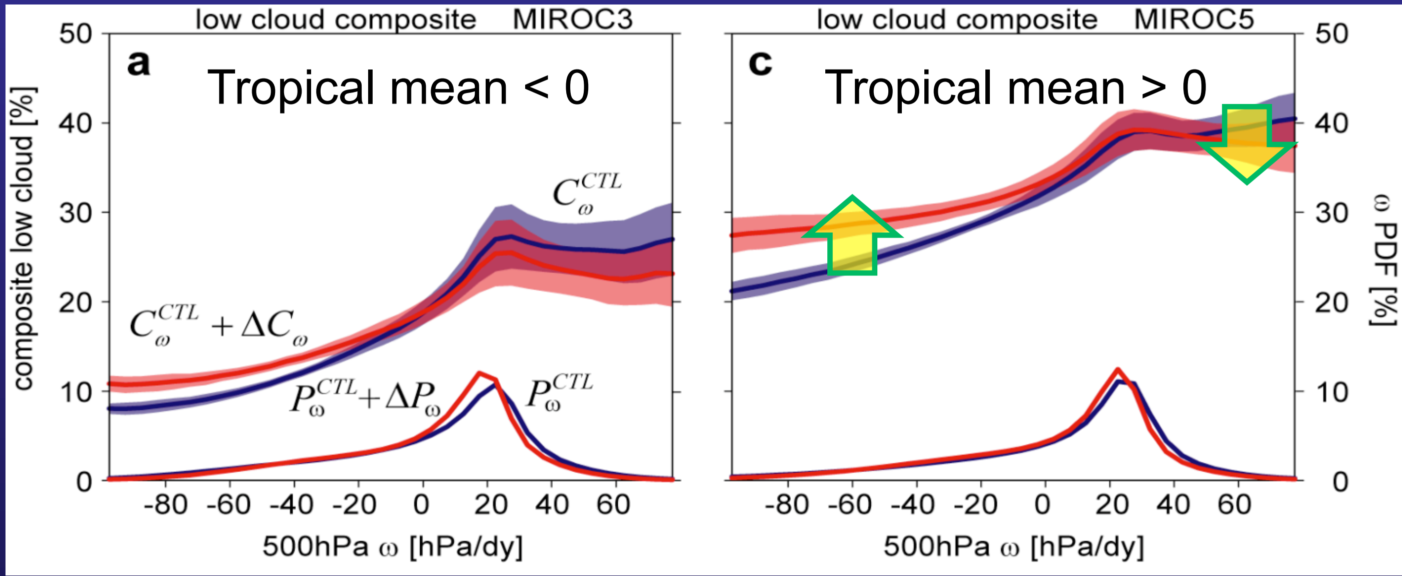
Fast response of low clouds

4xCO_2 runs
(20y ensemble)

Regime composite of low cloud wrt ω500

MIROC3 MIROC5

Low cloud amount [%]



500hPa ω

Watanabe et al. (2011, Clim Dyn)

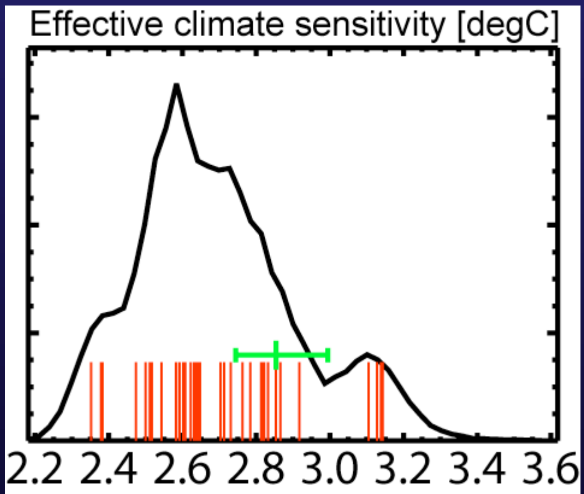
$$\Delta\tilde{C}_l \simeq \int \Delta P_\omega C_l^{CTL}(\omega)d\omega + \int P_\omega^{CTL}\Delta C_l(\omega)d\omega$$

Thermodynamic driving

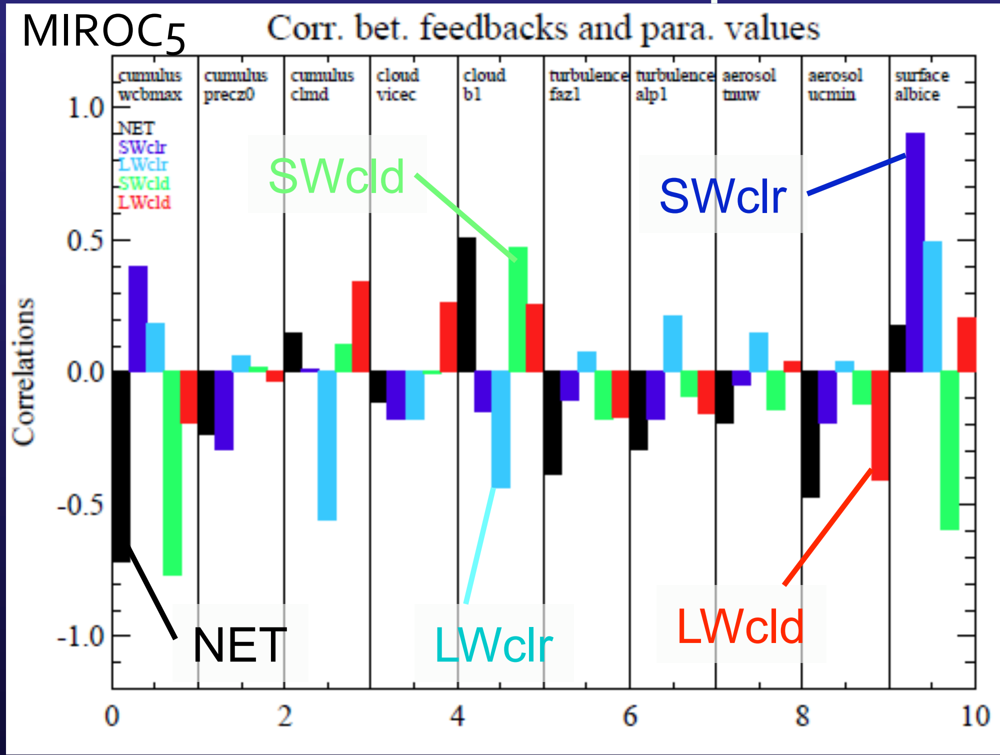
Tropical-mean changes in C_l & SWcld are due to a subtle difference between C_l decrease / increase over the subsidence / ascent regime

MIROC Perturbed Physics Ensembles (PPEs)

- **MIROC3.2 PPE** (JUMP project, Annan et al. 2005)
  - ✓ T20L20 slab CGCM
  - ✓ 13 parameters perturbed w/ EnKF
- **MIROC5 PPE** (Shiogama et al. 2011, submitted)
  - ✓ T42L40 full CGCM
  - ✓ 10 parameters perturbed w/ Latin hypercube + emulator



Corr. between feedbacks and parameters

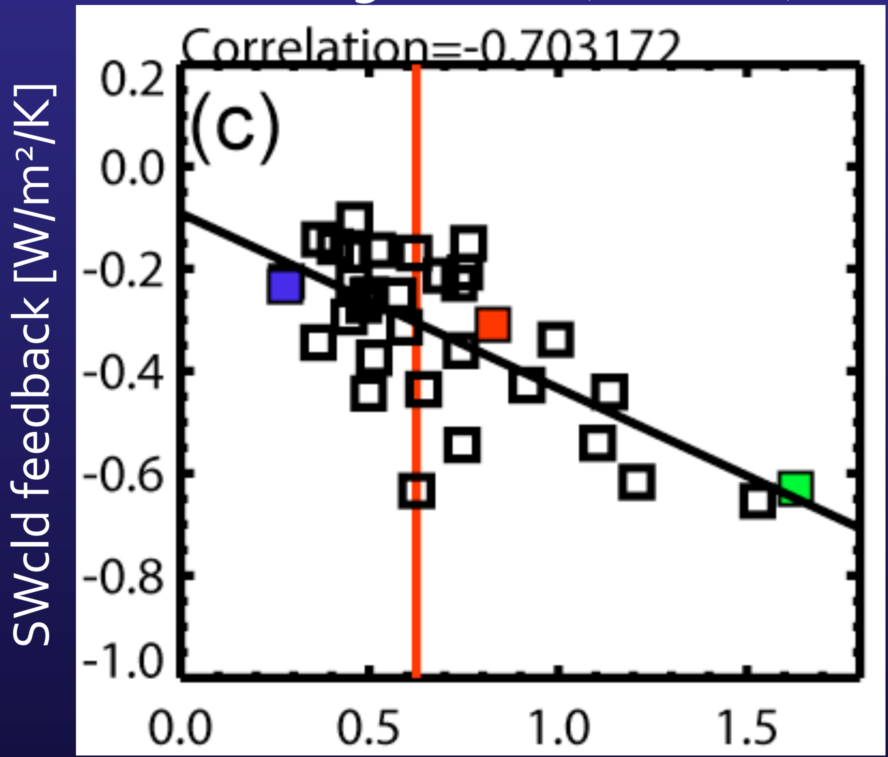


# of parameter

ENSO and climate sensitivity?

Reasons may be different in the two models, but a common feature of *strong ENSO in the control run <---> low CS*

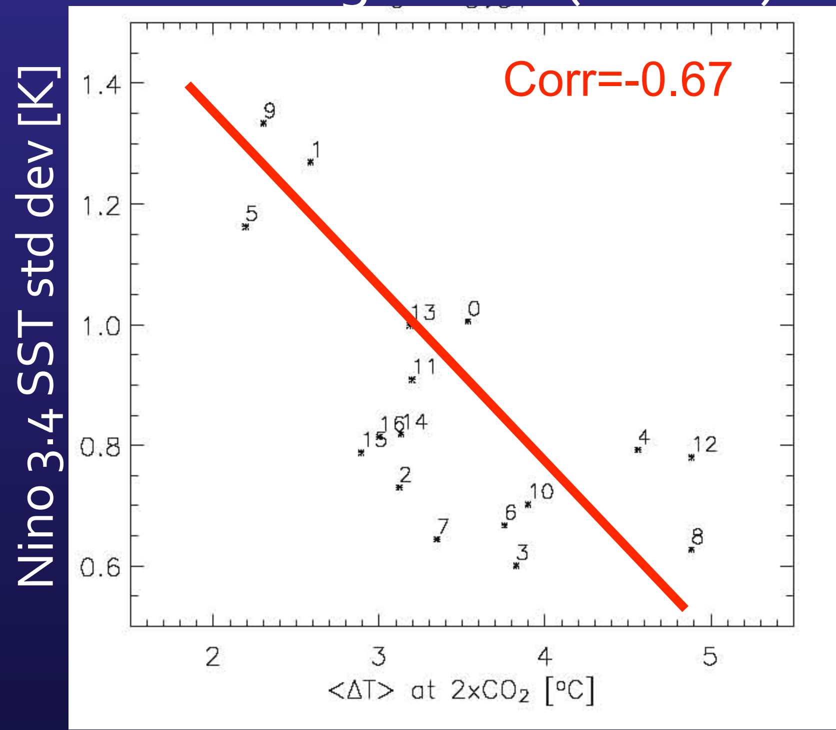
MIROC5 PPE-C (JUMP2)



Nino 3.4 SST std dev [K]

Shiogama et al. (2011, submitted)

HadCM3 PPE-C (QUMP)



Equilibrium climate sensitivity [K]

Toniazzo et al. (2008)

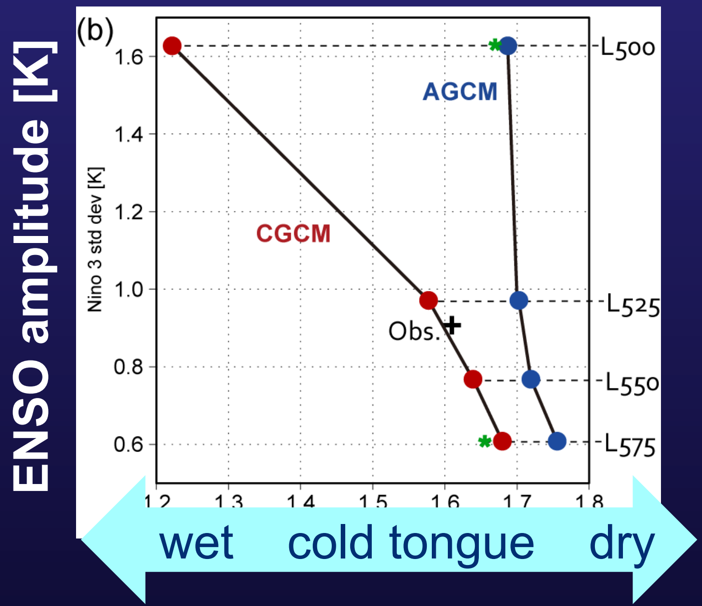
ENSO and climate sensitivity?

Compare 10 models having
* Largest negative SWcld feedback
* Smallest negative SWcld feedback

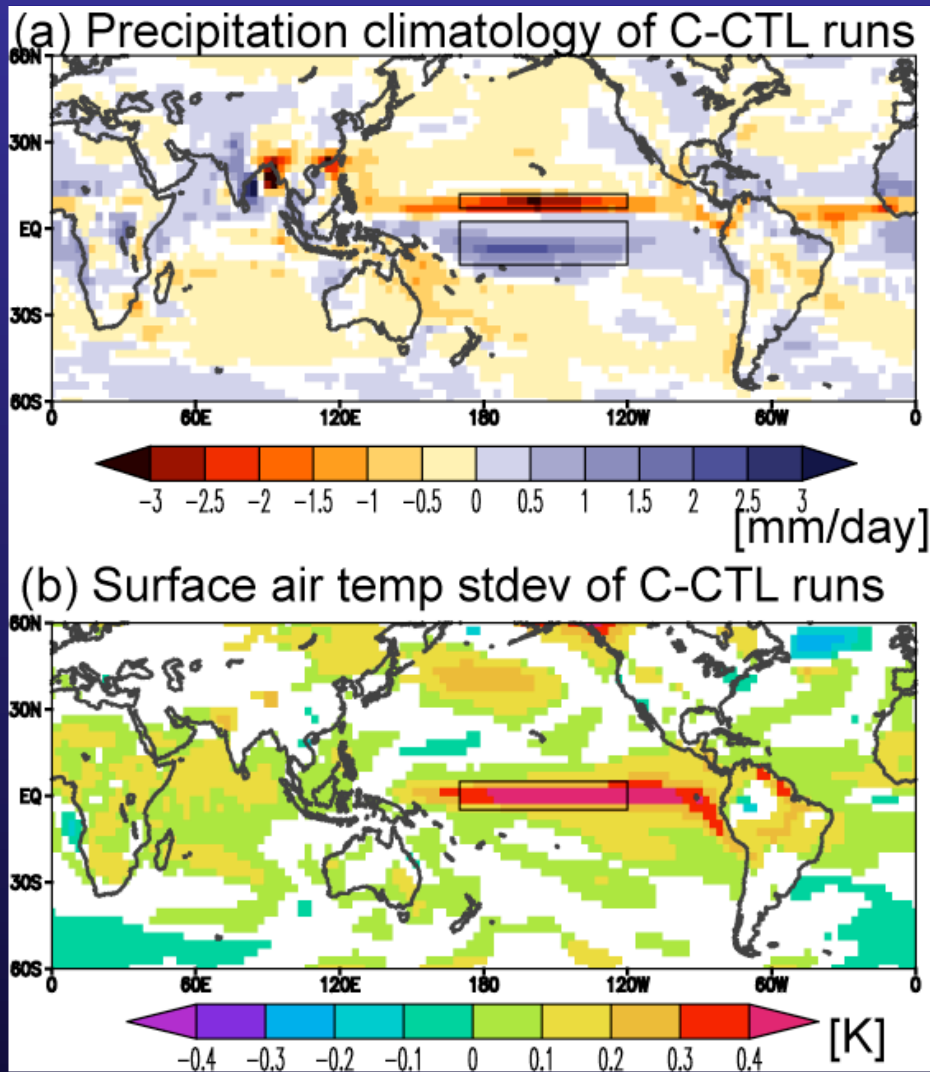
Larger SWcld feedback

⇕

Wetter mean state over the central equatorial Pacific & stronger ENSO



Watanabe et al. (2011, JC)



Shiogama et al. (2011, submitted)

Combined structural/parametric uncertainties

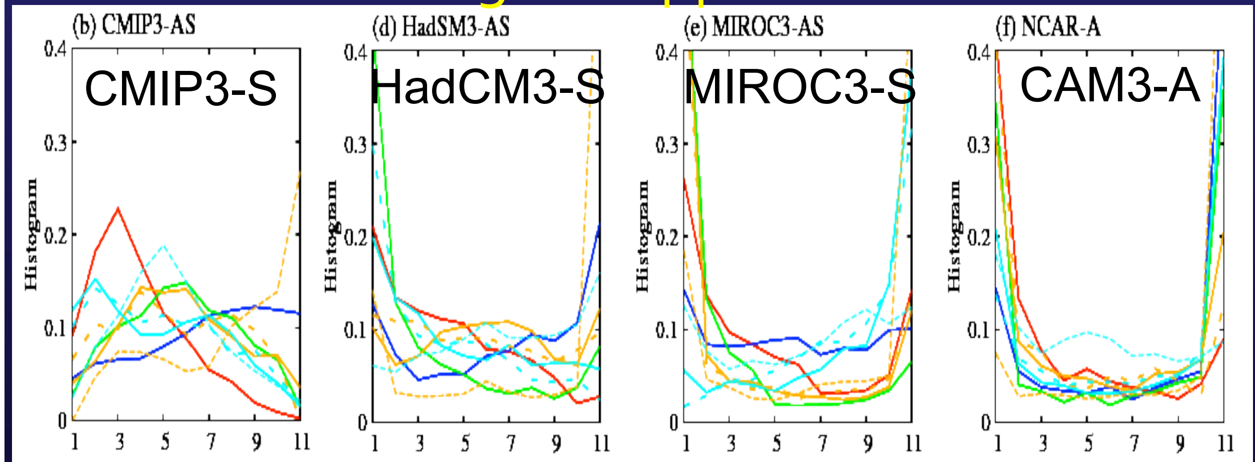
- PPE can be complementary to CMIP MME and has some advantages over MME
- PPE may also have disadvantages that

✓ The ensemble depends on the base model (Yokohata et al. 2011 JC)

✓ Model errors in the ensemble may not cancel each other

✓ May not be suitable for exploring feedback *mechanisms*

Rank histogram approach



Rank

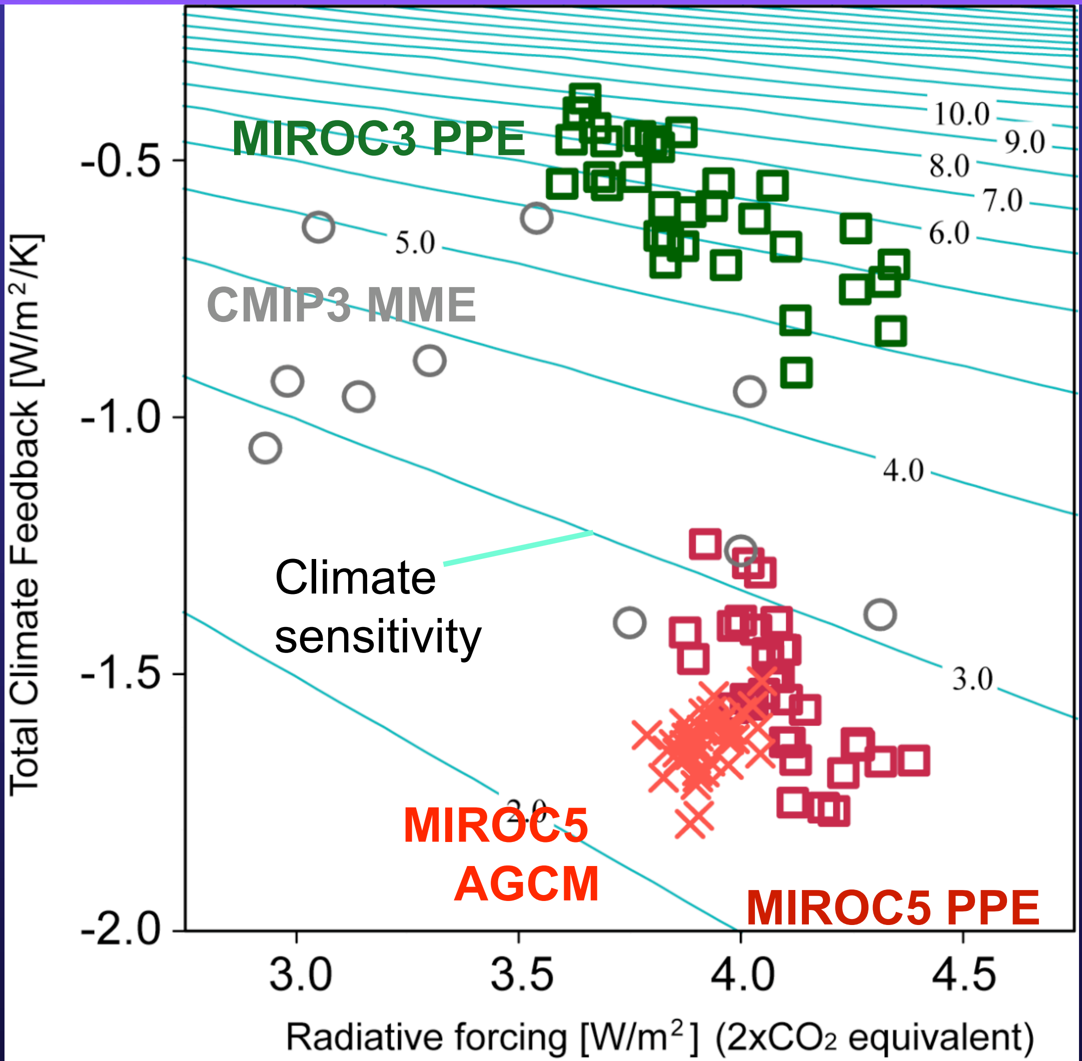
Yokohata et al. (2011, Clim Dyn)

✓ Ranks observations among ensembles
-> Histogram

✓ **Flat histogram**
= ensemble members are around the observation

✓ **Edge-peaked histogram**
= ensemble members over-/under-estimate observation

Forcing-Feedback in two PPEs



Multi-Physics Ensemble (MPE)

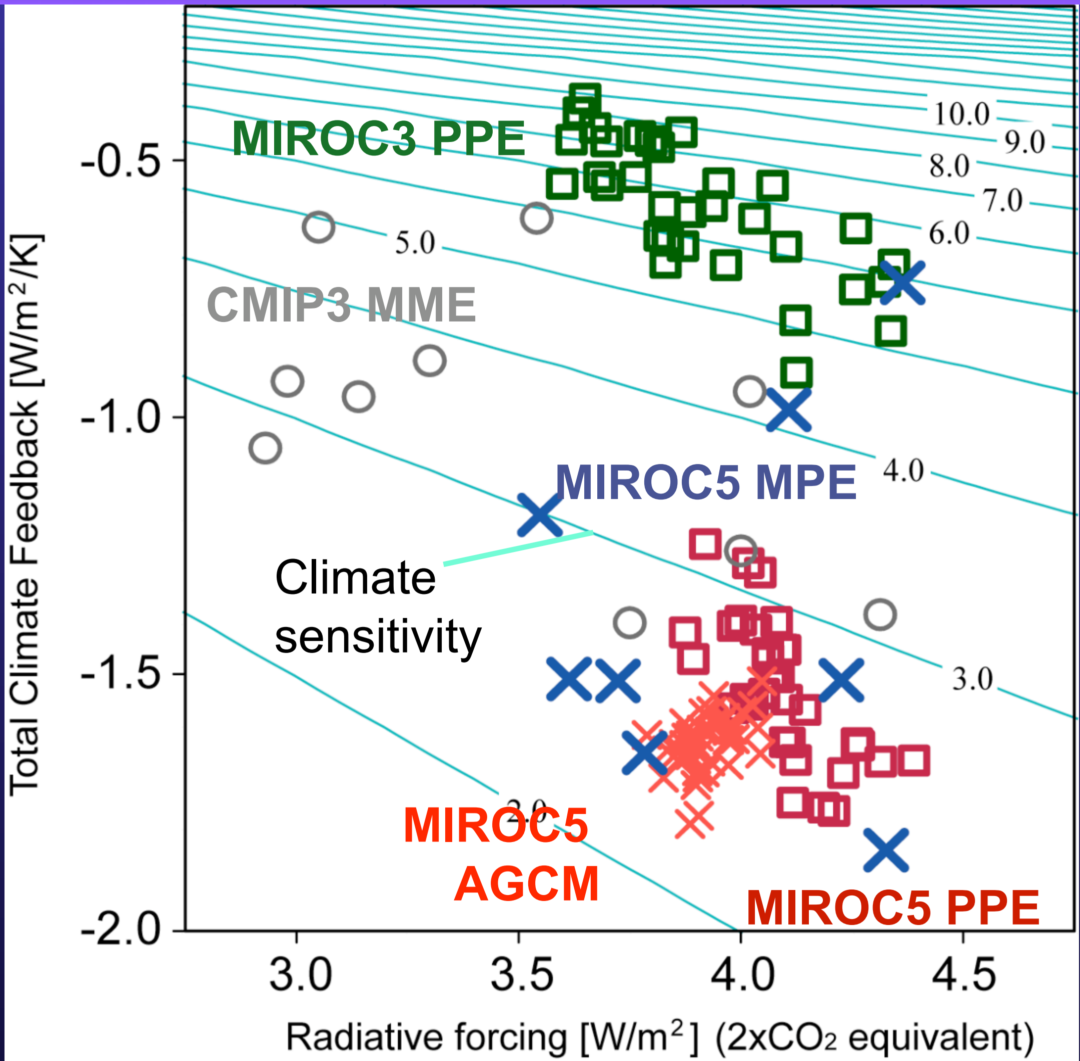
Replacing one or more schemes in MIROC5 w/ old ones:

- ✓ Std (=MIROC5)
- ✓ (old)CLD
- ✓ (old)CUM
- ✓ (old)VDF
- ✓ (old)CLD+CUM
- ✓ (old)CUM+VDF
- ✓ (old)CLD+VDF
- ✓ (old)CLD+CUM+VDF

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

Watanabe et al. (2011, submitted)

Forcing-Feedback in two PPEs



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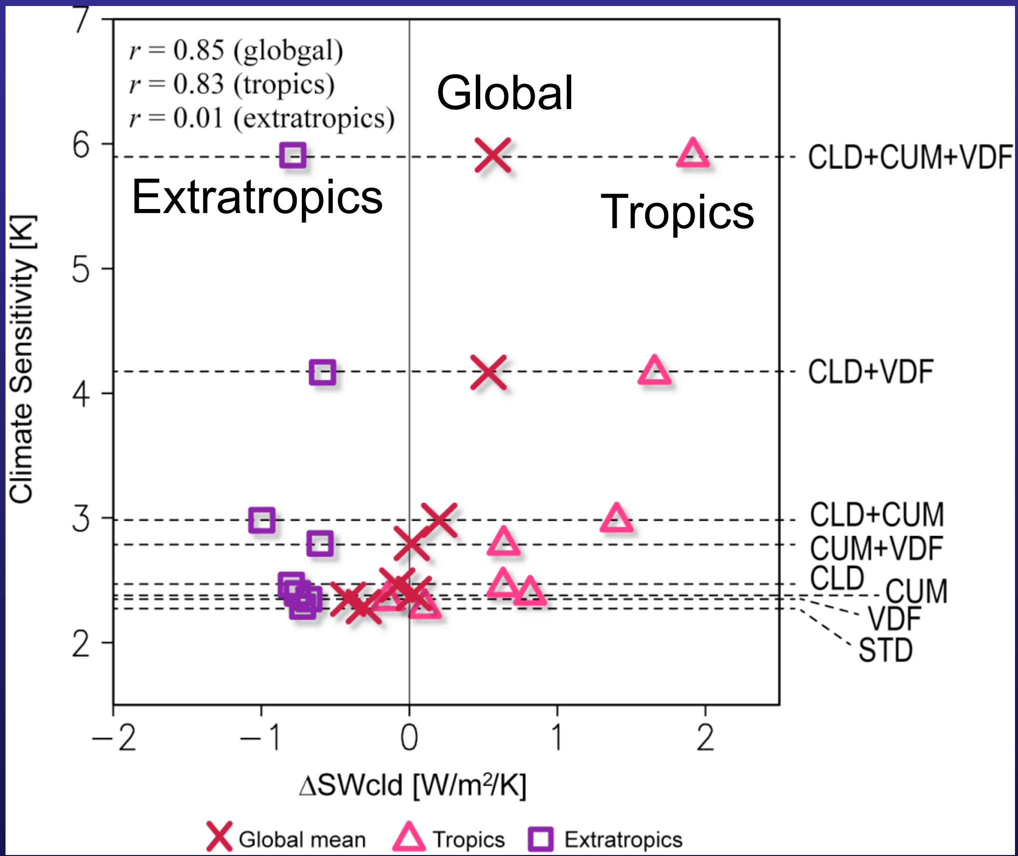
Watanabe et al. (2011, submitted)

MPE: Filling the gap between PPEs

Climate sensitivity vs SWcld feedback

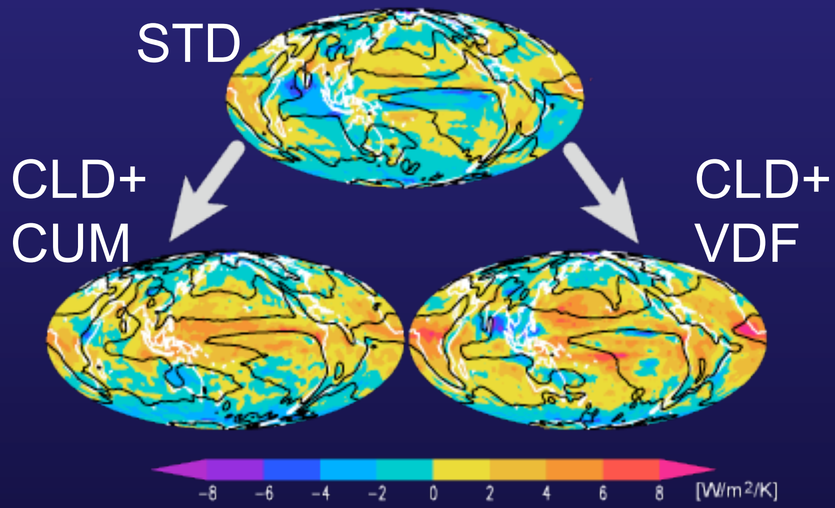


Watanabe et al. (2011, submitted to JC)

Processes are nonlinear, e.g.,

(old)CLD -> small impact
(old)VDF -> small impact
(old)CLD+VDF -> large impact!!

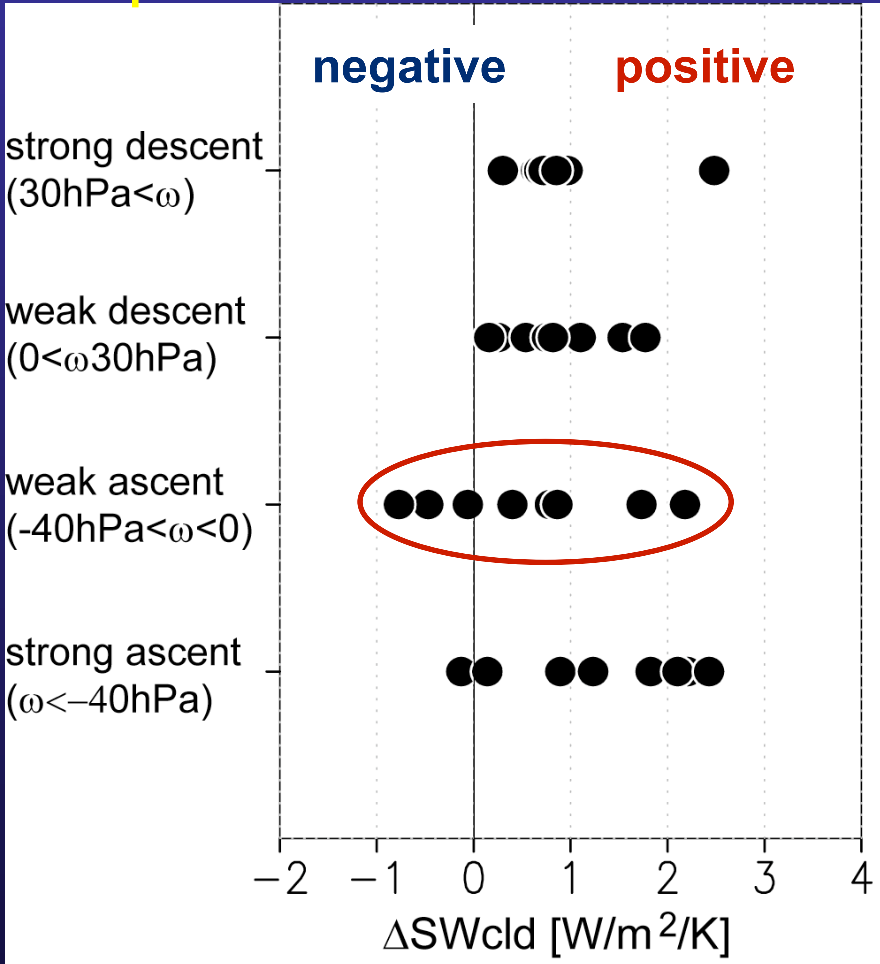
SWcld feedbacks



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

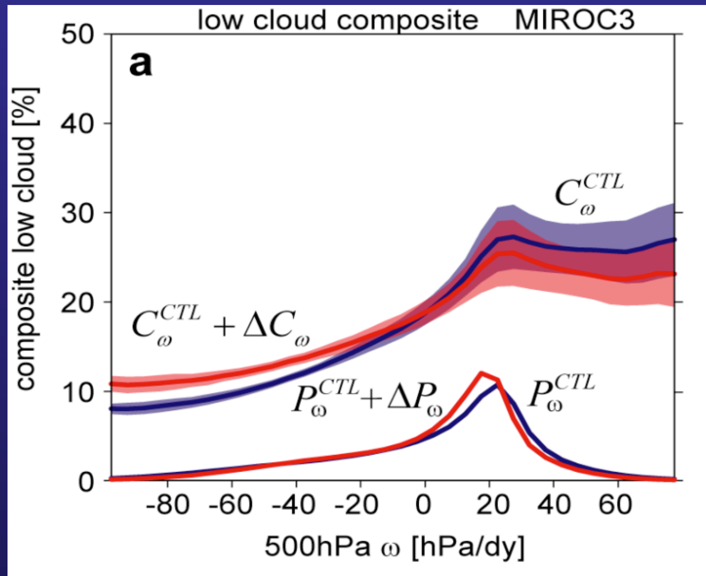
SWcld feedback in different circulation regimes

Composite SWcld feedback in MPE



Watanabe et al. (2011, submitted)

Composite low clouds in MiROC3 4xCO2

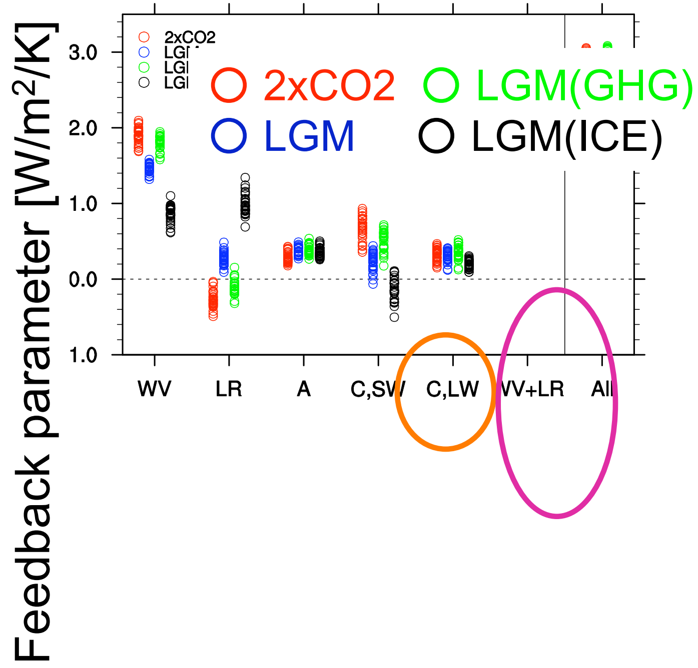


SWcld feedback appears to be robust (at least in MIROC3/5) for the subsidence regimes, but not for the convective regime!

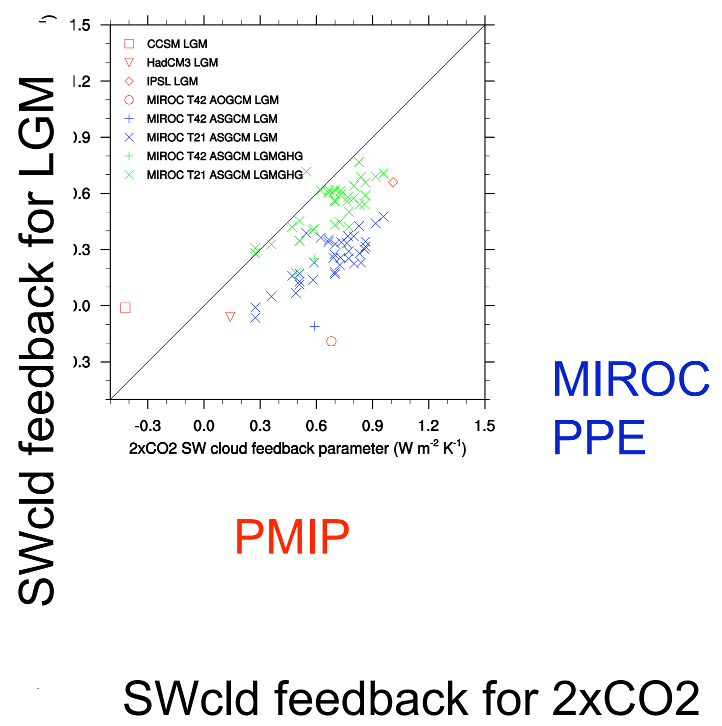
→ Trade cumulus response?

Can climate feedback be constrained with palaeoclimate simulations?

Feedback analysis based on MIROC3.2 PPE



SWcld values correlated for LGM & $2xCO_2$ in PPE (but not in PMIP2)



Yoshimori et al. (2011, JC)

✓ Different total feedback (hence ECS) for different forcing & mean climate

→ caution to use palaeo data to constrain ECS

Conclusions

Toward understanding sources of model's "uncertainty" in terms of the climate sensitivity & climate feedbacks,

- We emphasize thru the analysis of MIROC3.2/MIROC5/ CMIP3 an importance of:
  - ✓ identifying timescales of cloud response/feedback
  - ✓ distinguishing robust/fragile parts associated w/ cloud response/feedback
- Extensive use of various ensembles based on MIROC reveals
  - ✓ a connection between apparently independent phenomena (ENSO & climate sensitivity)
  - ✓ attribution of inconsistency among GCMs to individual processes/interactions

Recent publications

- ✓ Watanabe et al. 2010 JC (MIROC5)
- ✓ Yokohata et al. 2010 JC (MIROC3 PPE)
- ✓ Shiogama et al. 2011 CD (MIROC5 PPE) *
- ✓ Watanabe et al. 2011 ASL (MIROC5 20C)
- ✓ Watanabe et al. 2011 CD (MIROC3/5) #
- ✓ Watanabe et al. 2011 JC (MPE) *
- ✓ Yoshimori et al. 2011 JC (MIROC3 PPE) #
- ✓ Yokohata et al 2011 CD (MIROC3 PPE/MME) #

* submitted, # in press

All available at

http://amaterasu.ees.hokudai.ac.jp/~fswiki/pub/wiki.cgi?page=CMIP5

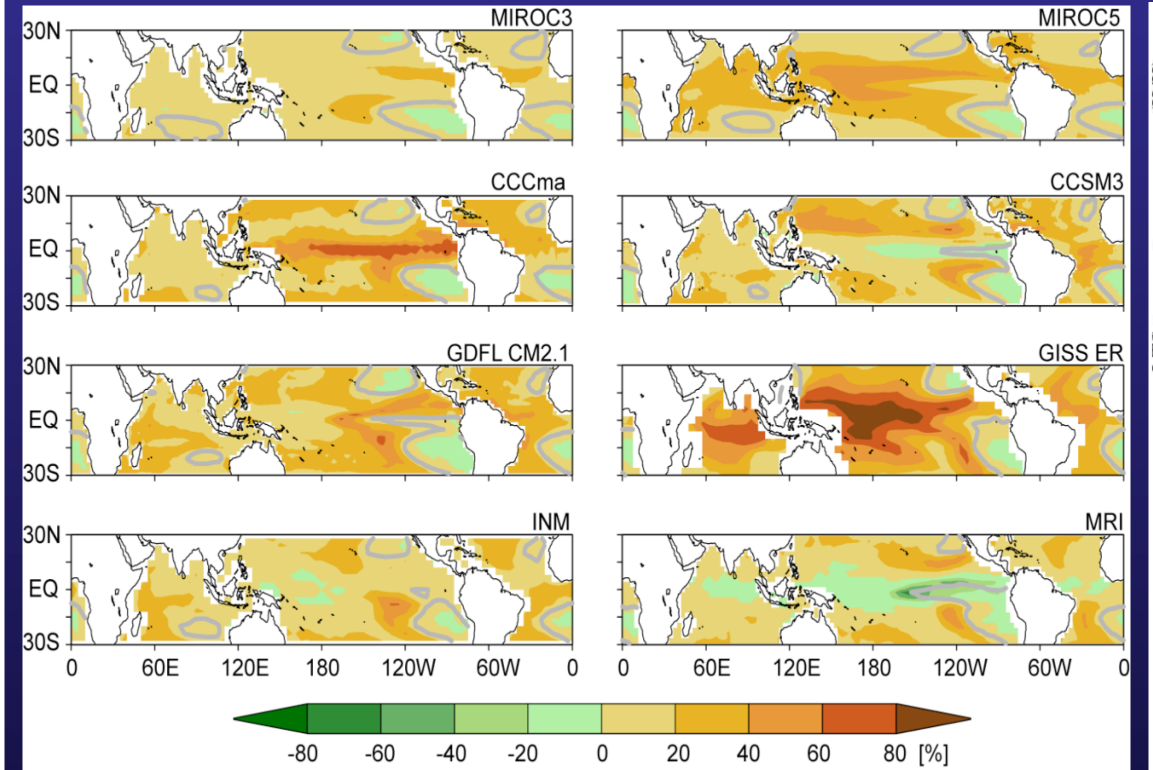
ID **guest**

Password **miroc**

backup

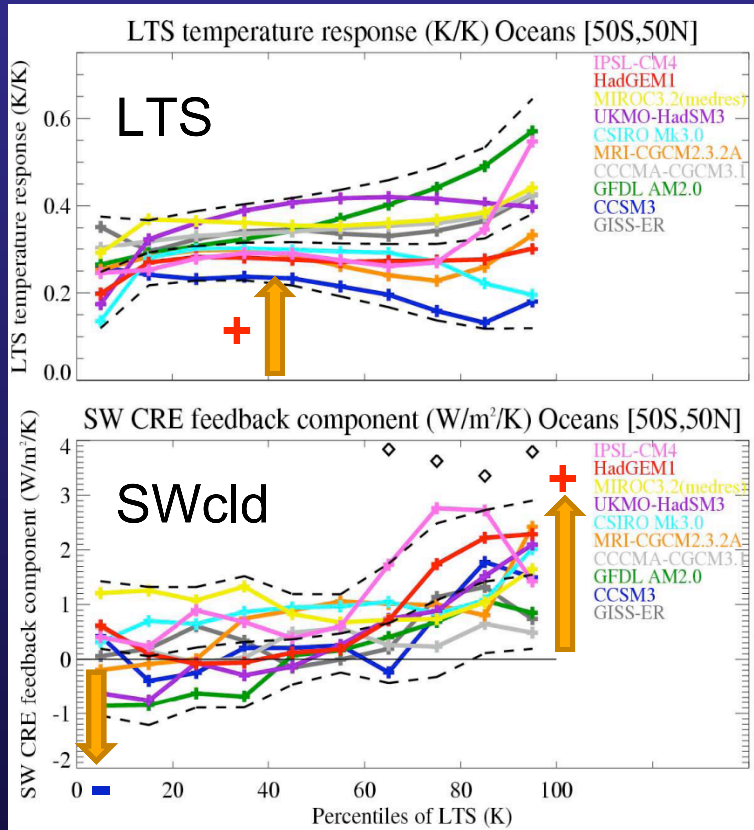
What is robust? What is not robust?

Change in stable regime frequency in CFMIP1



Watanabe et al. (2011, Clim Dyn)

Sorted responses in CFMIP1



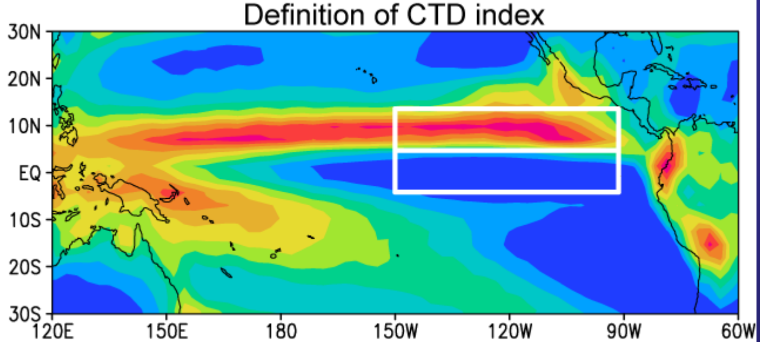
Unstable ⟷ Stable

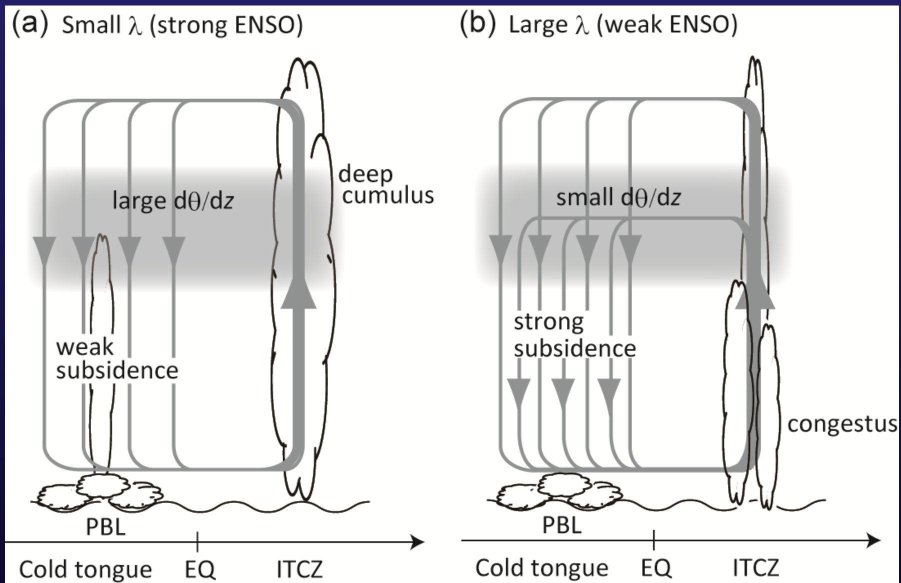
Courtesy of M Webb

- ✓ Increasing LTS: sign robust (but not magnitude)
- ✓ Change in SWcld: fragile even sign

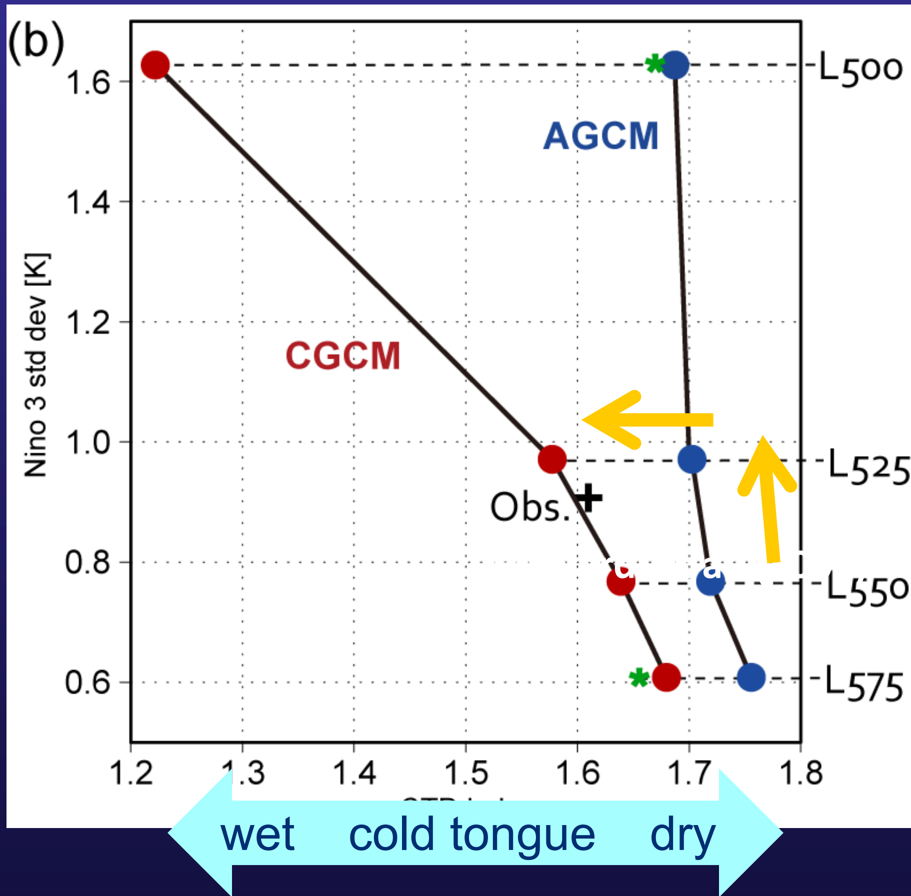
ENSO control mechanism in MIROC5

Cold tongue dryness (CTD) index





ENSO & mean state error



Direct effect of convection

Coupled feedbacks

Watanabe et al. (2011, JC)

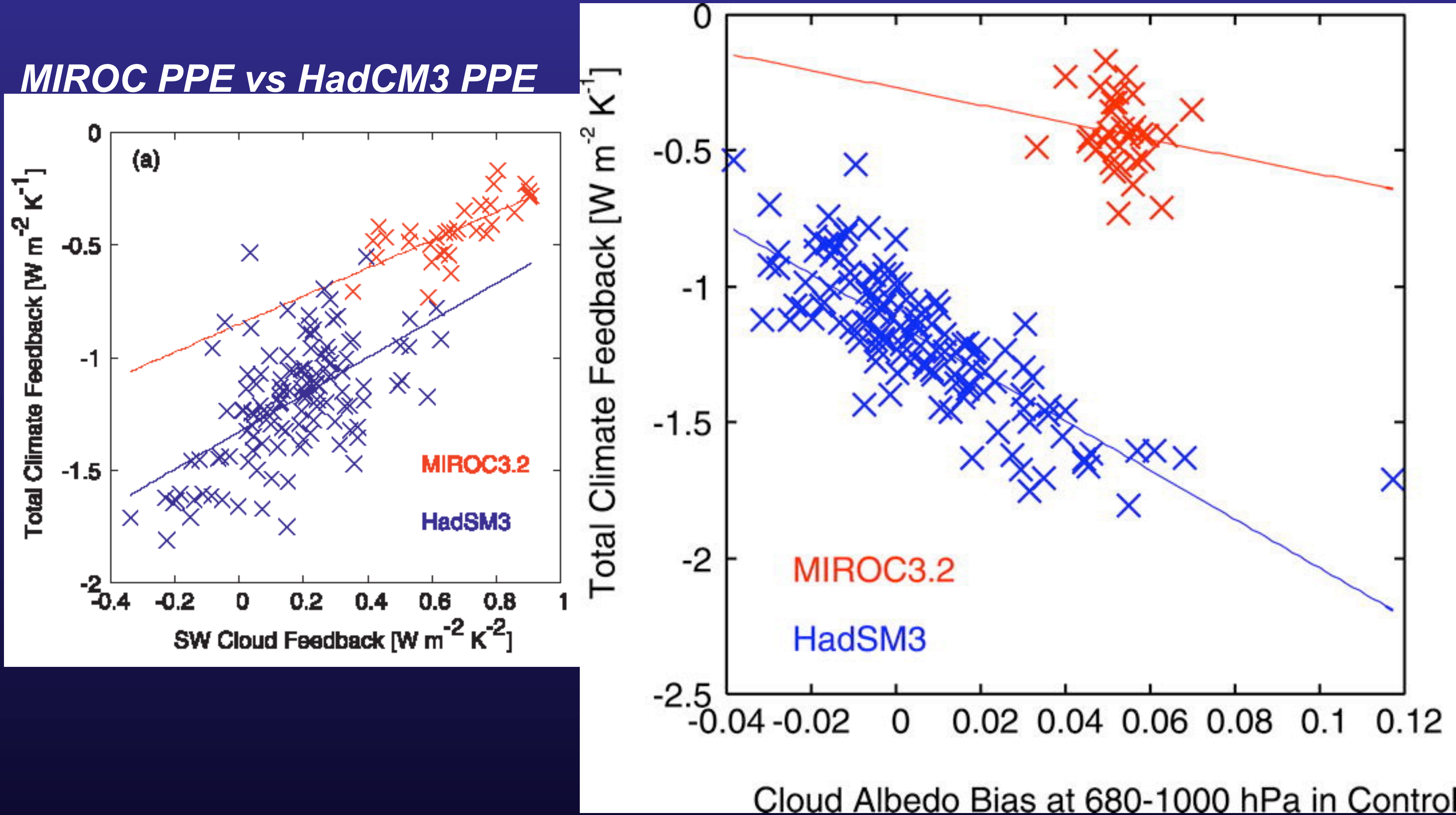
MIROC updates after AR4

		MIROC3.2	MIROC5
Atmos.	**Dynamical core**	Spectral+semi-Lagrangian (Lin & Rood 1996)	Spectral+semi-Lagrangian (Lin & Rood 1996)
	V. Coordinate	Sigma	Eta (hybrid sigma-p)
	Radiation	2-stream DOM 37ch (Nakajima et al. 1986)	2-stream DOM 111ch (Sekiguchi et al. 2008)
	Cloud	Diagnostic (LeTreut & Li 1991) + Simple water/ice partition	Prognostic PDF (Watanabe et al. 2009) + Ice microphysics (Wilson & Ballard 1999)
	Turbulence	M-Y Level 2.0 (Mellor & Yamada 1982)	MYNN Level 2.5 (Nakanishi & Niino 2004)
	Convection	Prognostic A-S + critical RH (Pan & Randall 1998, Emori et al. 2001)	Prognostic AS-type, but original scheme (Chikira & Sugiyama 2010)
	Aerosols	simplified SPRINTARS (Takemura et al. 2002)	SPRINTARS + prognostic CCN (Takemura et al. 2009)
Land/ River		MATSIRO+fixed riv flow	new MATSIRO+variable riv flow
Ocean		COCO3.4	COCO4.5
Sea-ice		Single-category EVP	Multi-category EVP

Combined structural/parametric uncertainty

Understanding how parameter-driven uncertainties in PPEs depend on structural properties of the model

MIROC PPE vs HadCM3 PPE



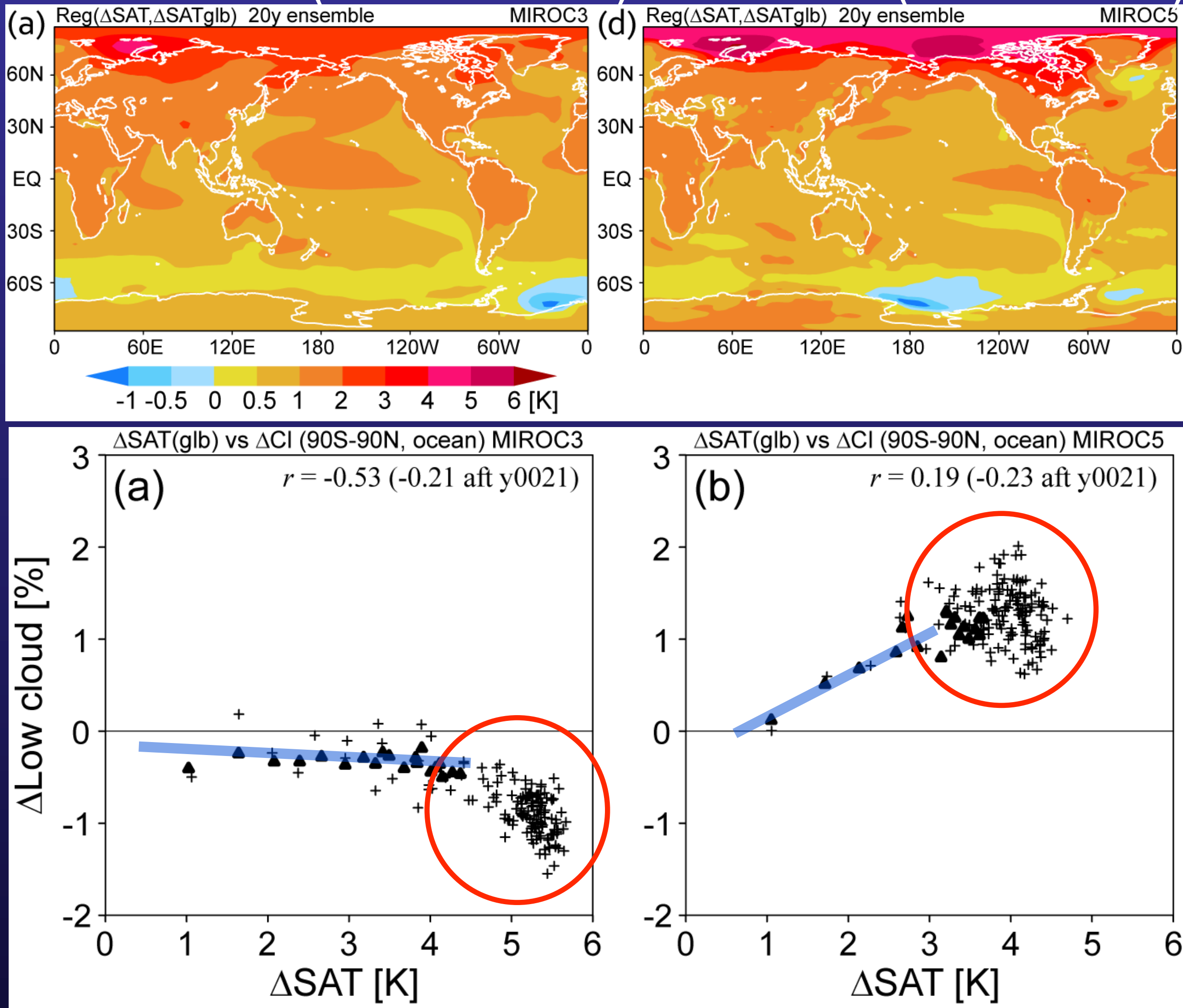
Yokohata et al. (2011, JC)

Global warming patterns

4xCO2 runs

MIROC3 (10 members) MIROC5 (6 members)

Reg(ΔSAT, ΔSATg)



+ ann. mean, single run (150y)

▲ ann. mean, ensemble avg (20y)

ΔSAT_g may not explain global-mean ΔC_l except for initial years

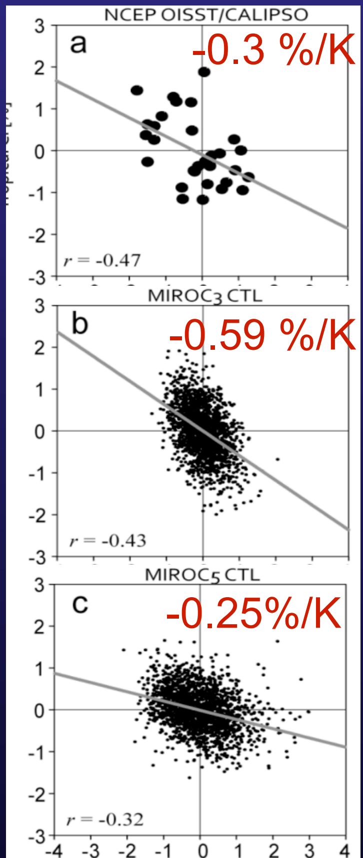
Watanabe et al. (2011, Clim Dyn)

Natural low-cloud (C_l) variability

Obs/CTL runs

Leading SVD

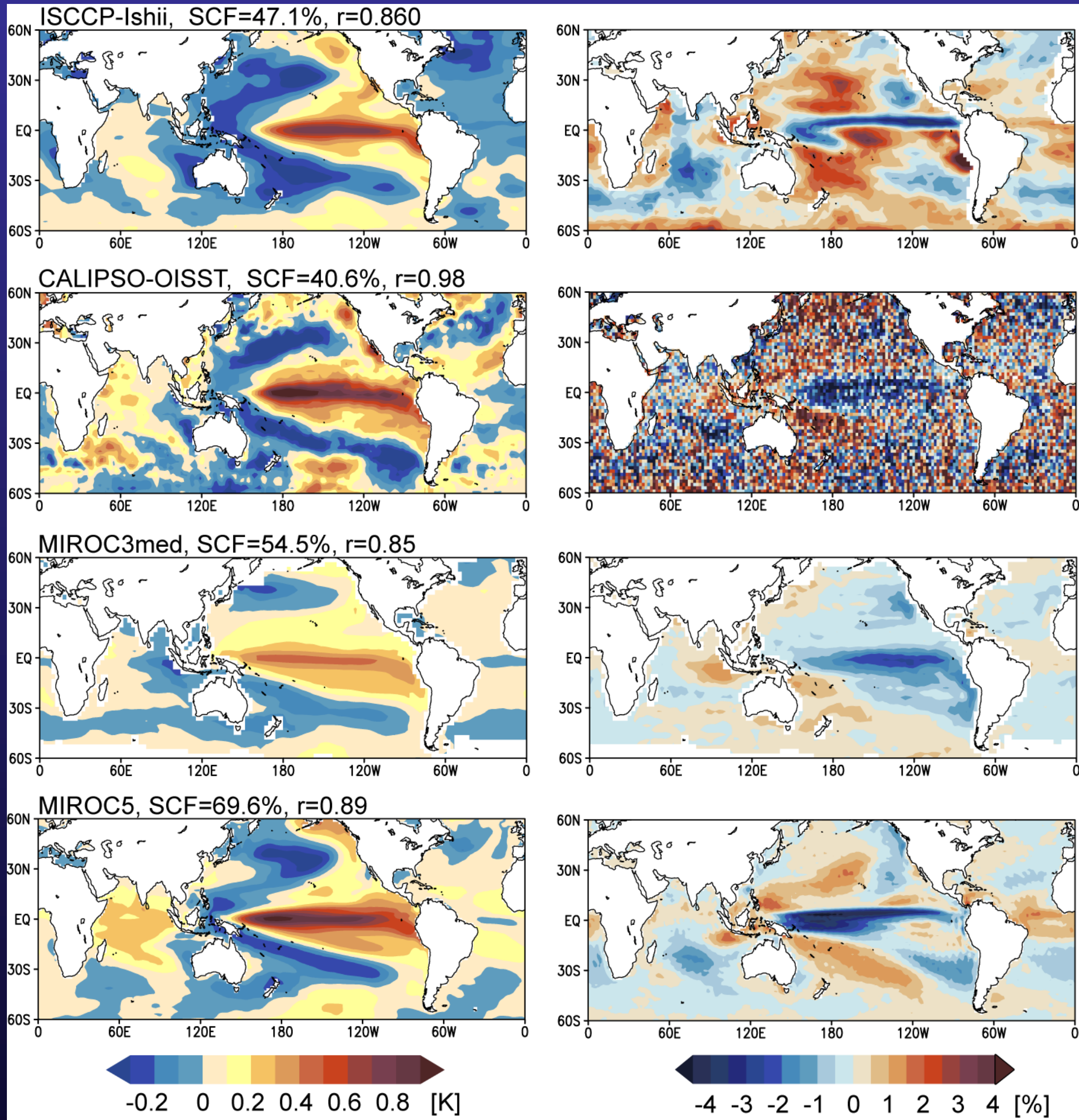
Tropical-mean Cl



Nino3 SST

SST anomaly

C_l anomaly



Ishii SST/ ISCCP

OISST/ CALIPSO

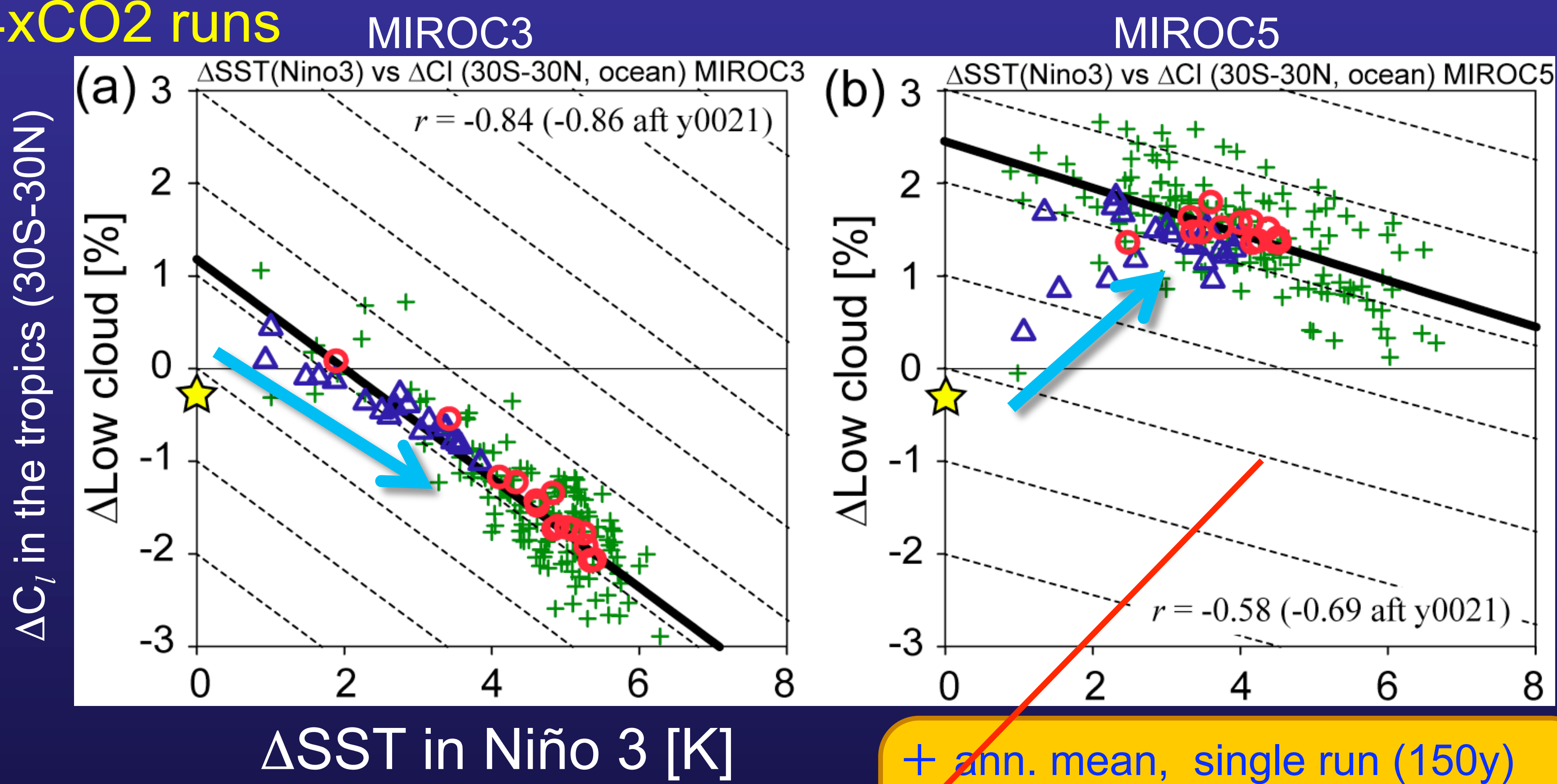
MIROC3 CTL

MIROC5 CTL

Watanabe et al. (2011, Clim Dyn)

Three timescales of low-cloud changes

4xCO2 runs



+ ann. mean, single run (150y)
○ decadal mean, single run
△ ann. mean, ensemble avg (20y)
★ initial month of △

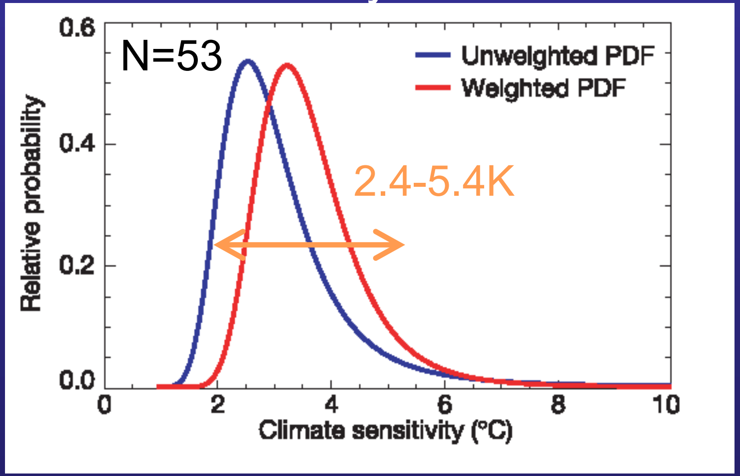
- ✓ Tropospheric adjustment
- ✓ Slow response (> 20y): $\left(\partial C_l' / \partial T_s'\right)_{CTL}$ matters!
- ✓ Fast response (< 10y): opposite between the models

Parametric uncertainty

Perturbed Physics Ensemble (PPE)

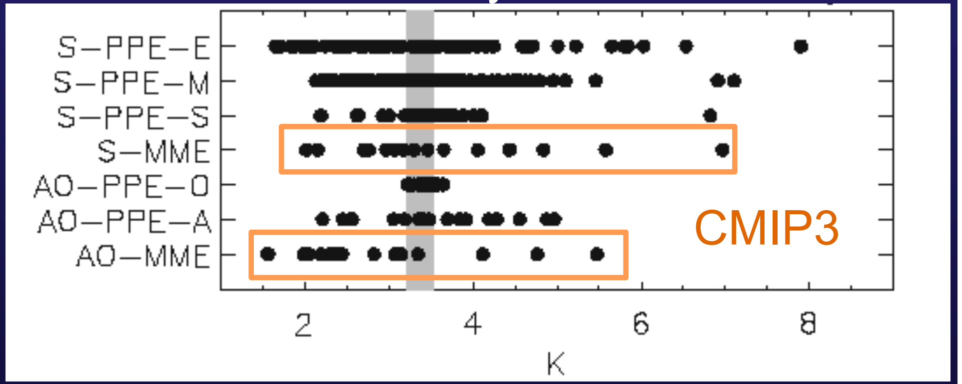
- ✓ Complementary ensemble to CMIP MME
- ✓ Designed for systematic sampling of uncertainty in a single model framework
- ✓ Some advantages over the "ensemble of opportunity"
- ✓ PPEs have been done with
  - HadCM3/HadSM
  - NCAR CAM3.x/4
  - MIROC3.2/5
  - ECHAM5
- ✓ Difference in parameter sets & perturbation strategy

Climate sensitivity in HadSM PPE



Murphy et al. (2004)

Climate sensitivity in QUMP & CMIP3



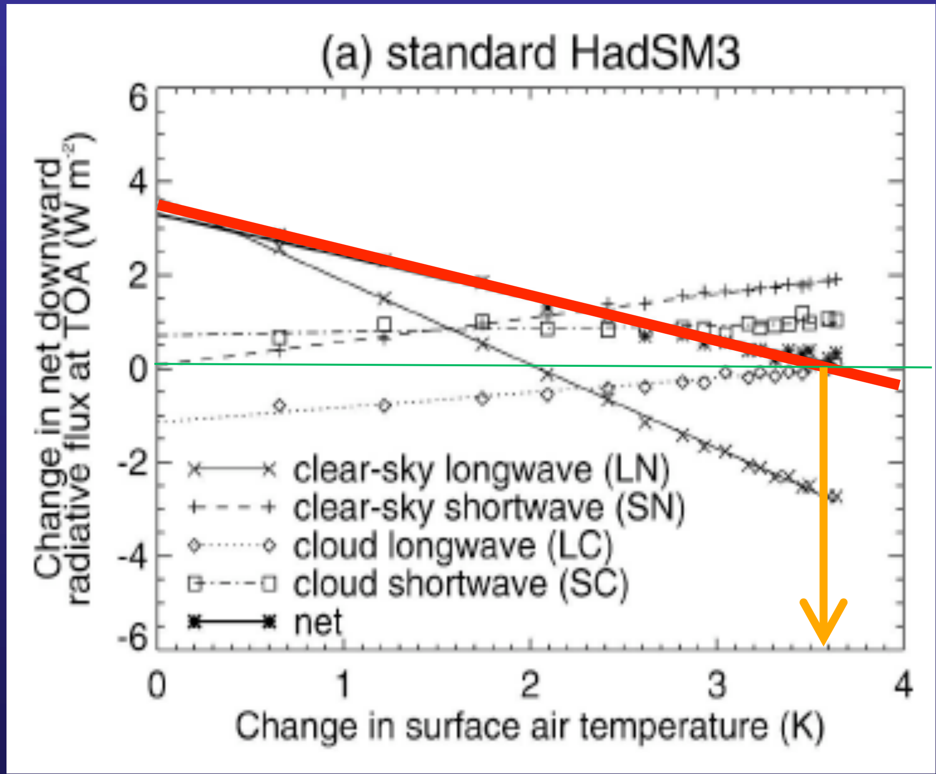
Collins et al. (2010)

How to evaluate climate sensitivity?

- In a CGCM 2xCO_2 experiment (=>20y),

  $N = F + \alpha \Delta T$

  and plot N against ΔT
- Assuming constant F and α on short timescale
- N can be decomposed into SW, LW and their clear-sky, cloud components



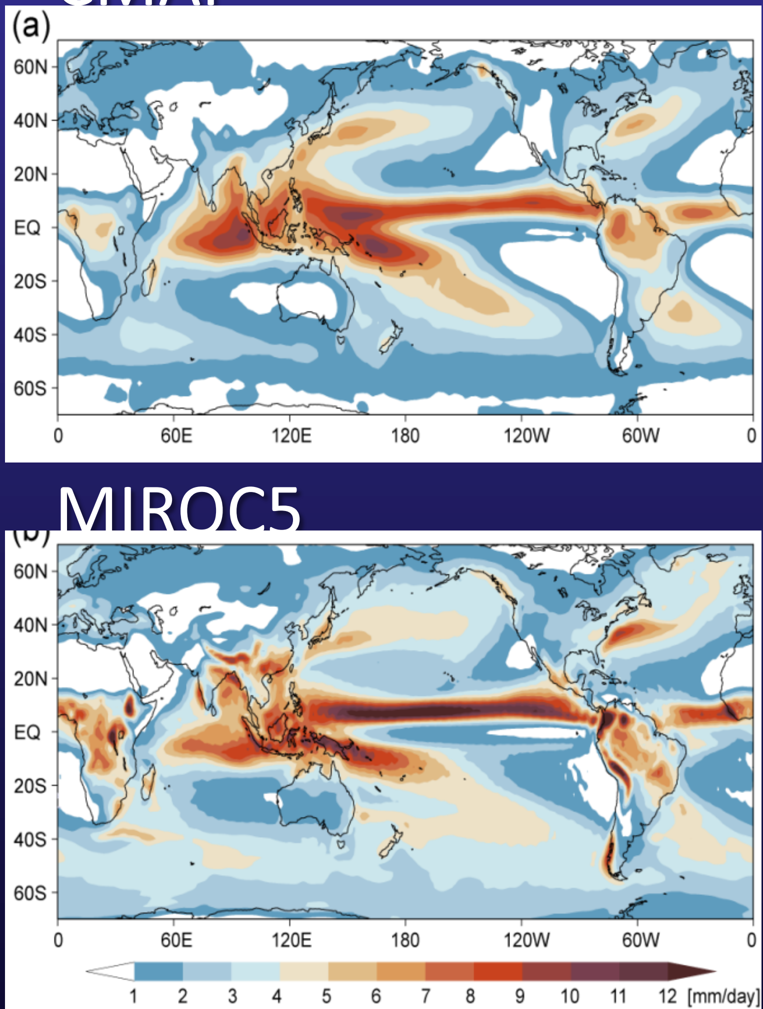
Gregory and Webb (2008)

- **Cloud component is surprising: F_{LC} and F_{SC} are non-zero!**
- This caused by rapid local changes to the vertical temperature profile due to the altered radiative heating, with consequent changes to stability, vertical mixing, and the moisture profile.
- Cloud contribution to F = "tropospheric adjustment" of CO2 forcing

Mean climatology

Annual mean precipitation

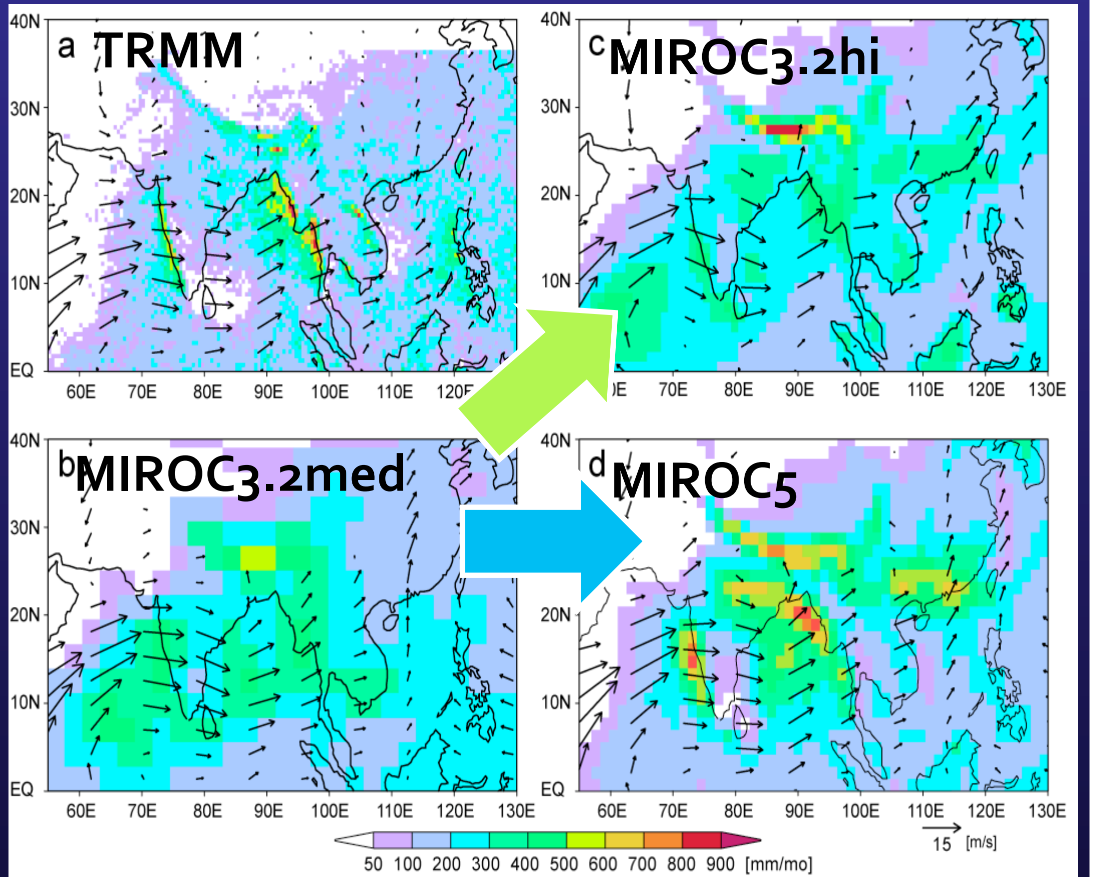
CMAP



MIROC5

Watanabe et al. (2010, JC)

JJA precipitation

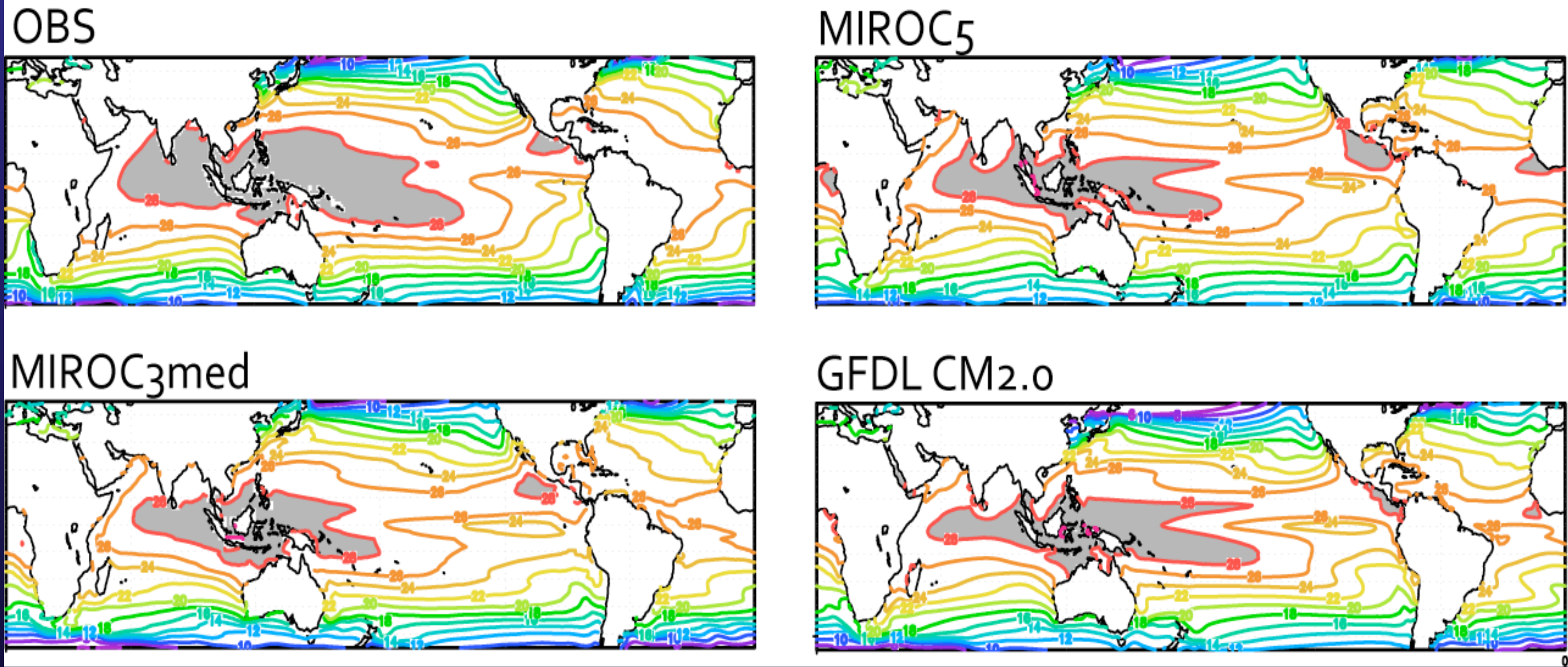


✓Effect of increased resolution

✓Effect of the new model physics

20C mean SST

1961-1990 annual avg. from 20C run



Natural low-cloud variability

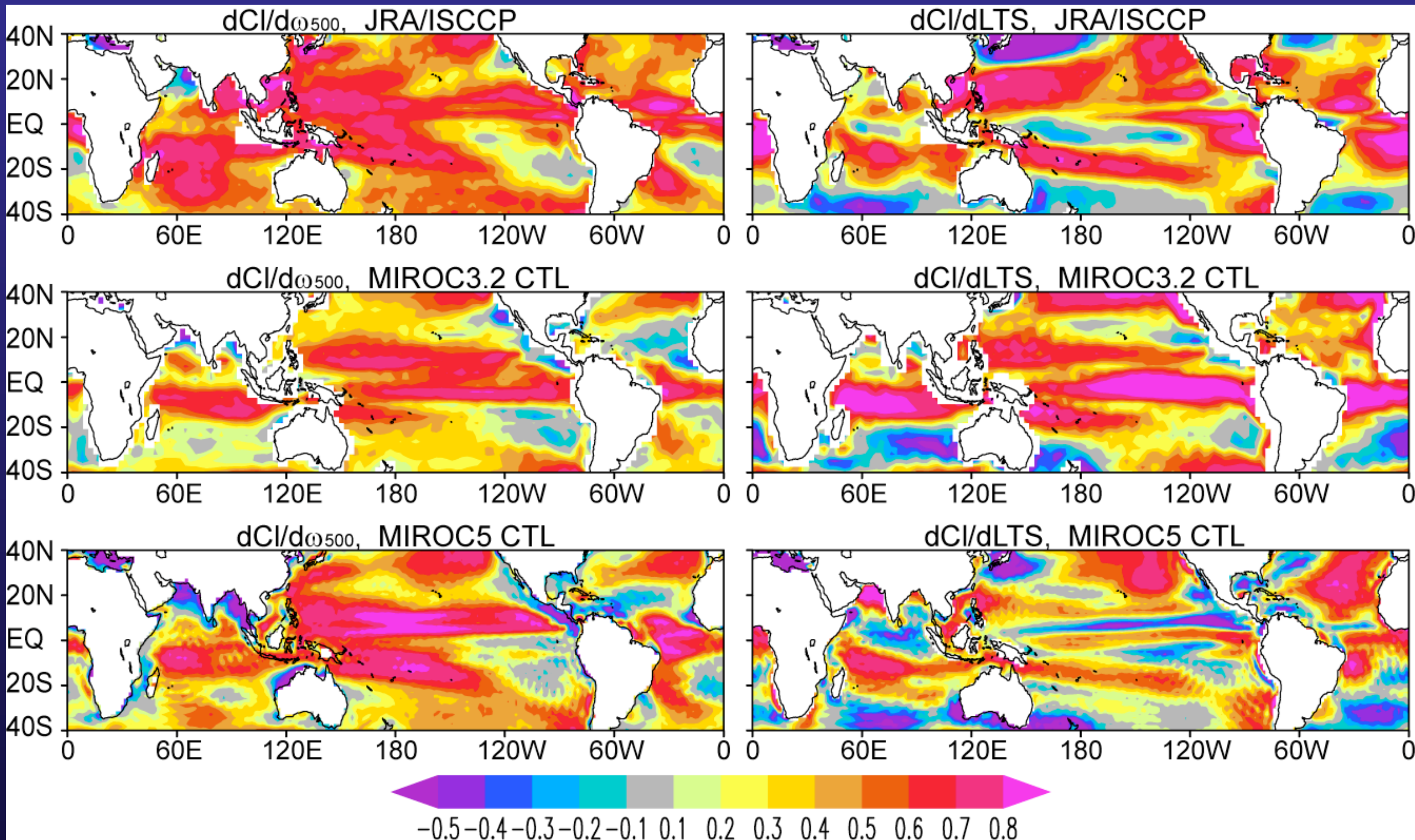
Obs/CTL runs

Local Cor (C_l, ω500) Local Cor (C_l, LTS)

JRA/ ISCCP

MIROC3 CTL

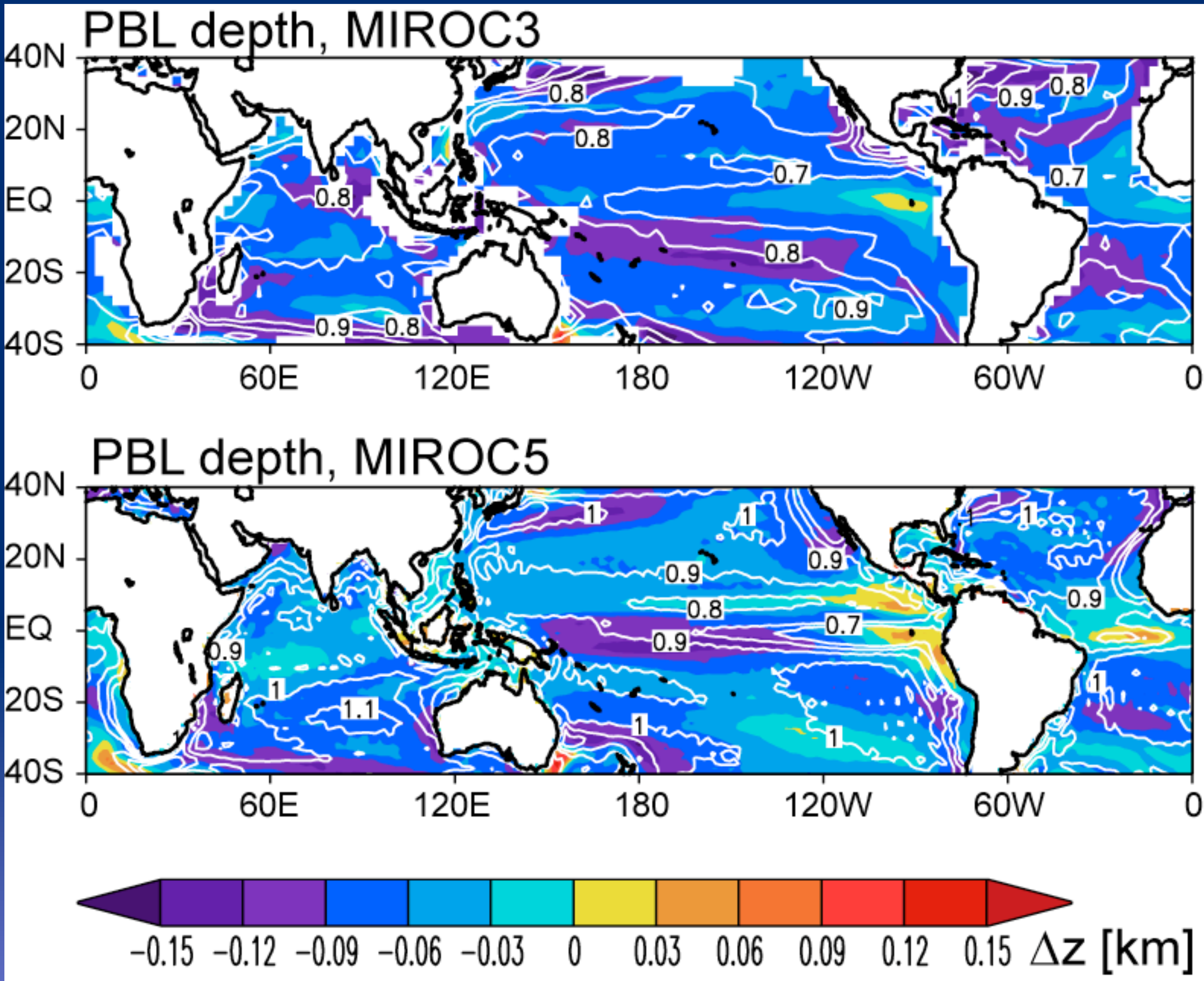
MIROC5 CTL



Watanabe et al. (2011, Clim Dyn)

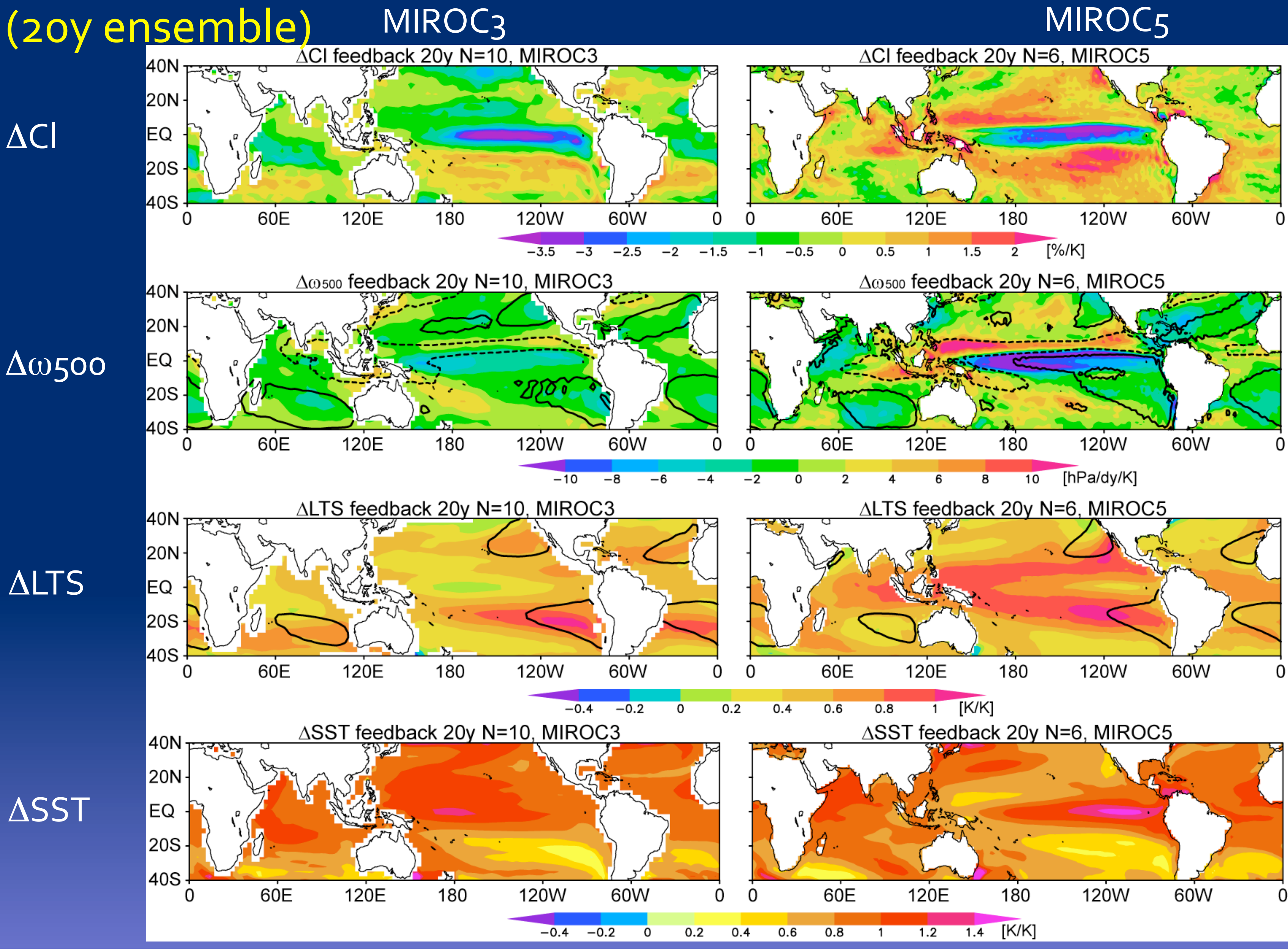
Fast response of low clouds

Change in PBL depth



Fast response of low clouds

4xCO2 runs (20y ensemble)



MIROC5 PPE: How to construct?

1. AGCM-CTL runs w/ min/max values of each parameter, estimating changes in the TOA net radiation imbalance

2. Generate the potential parameter sets by large Latin hypercube sampling (5000 samples)

3. Statistically emulate TOA imbalance at TOA for each sample by using ATL-CTL runs

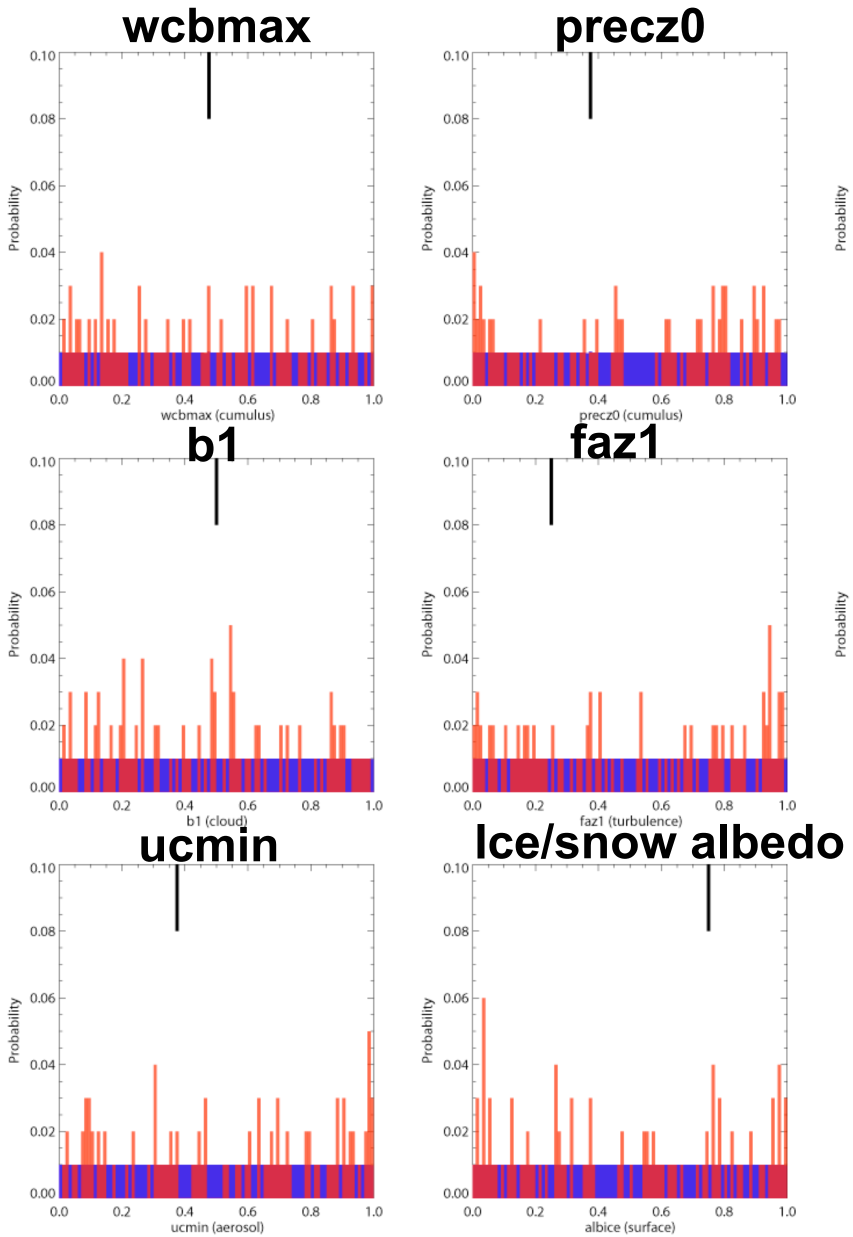
4. Select samples w/ smallest TOA imbalance, and a post process eliminating "very close" parameter values.

5. Repeat (4) to select 100 subsets.

6. Perform AOGCM CTL and 4xCO_2 runs w/ selected 100 *low-imbalance* parameter sets without flux adjustment.

Shiogama et al. (2011, submitted)

MIROC5 PPE: Sampled parameter values



Latin Hypercube Sampling

Suppressed Imbalance Sampling

Sampled values are not concentrated in small subspaces.

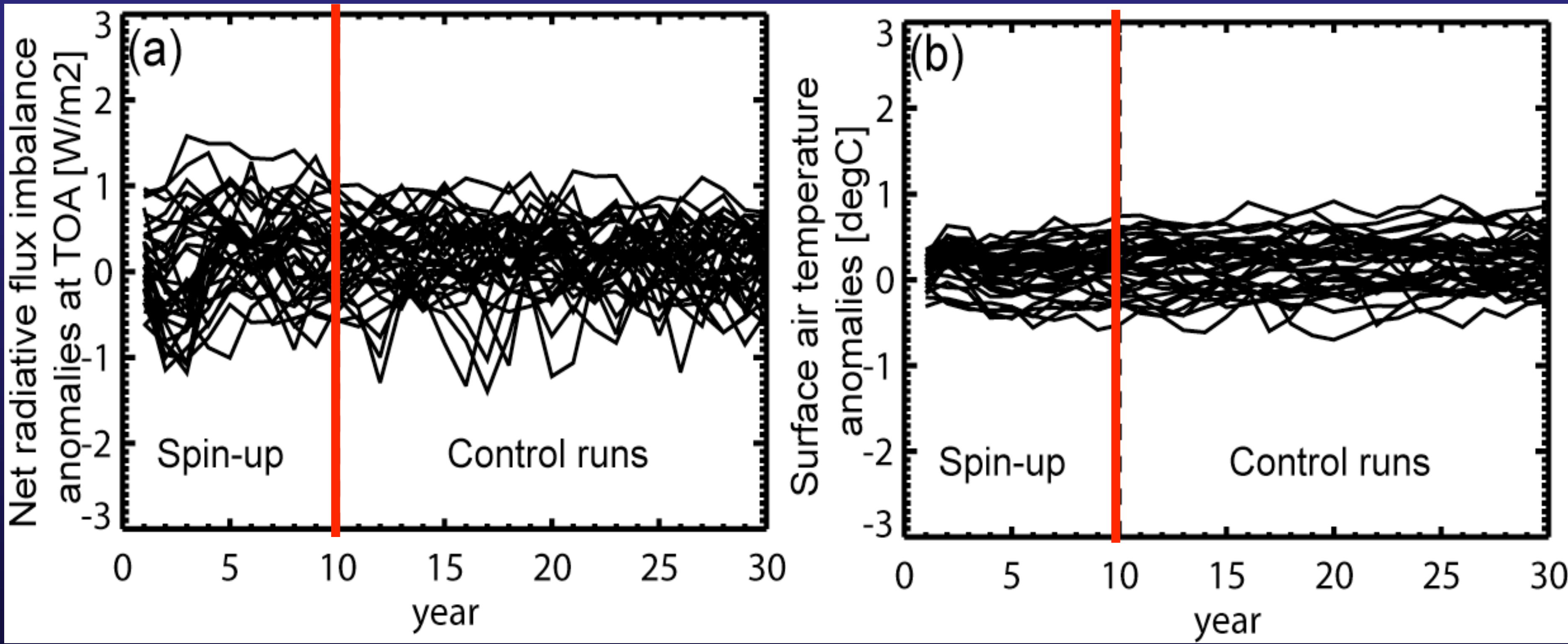
Shiogama et al. (2011, submitted)

MIRROC5 PPE

CGCM-CTL runs (anomalies from the run1=ref)

TOA radiative imbalance

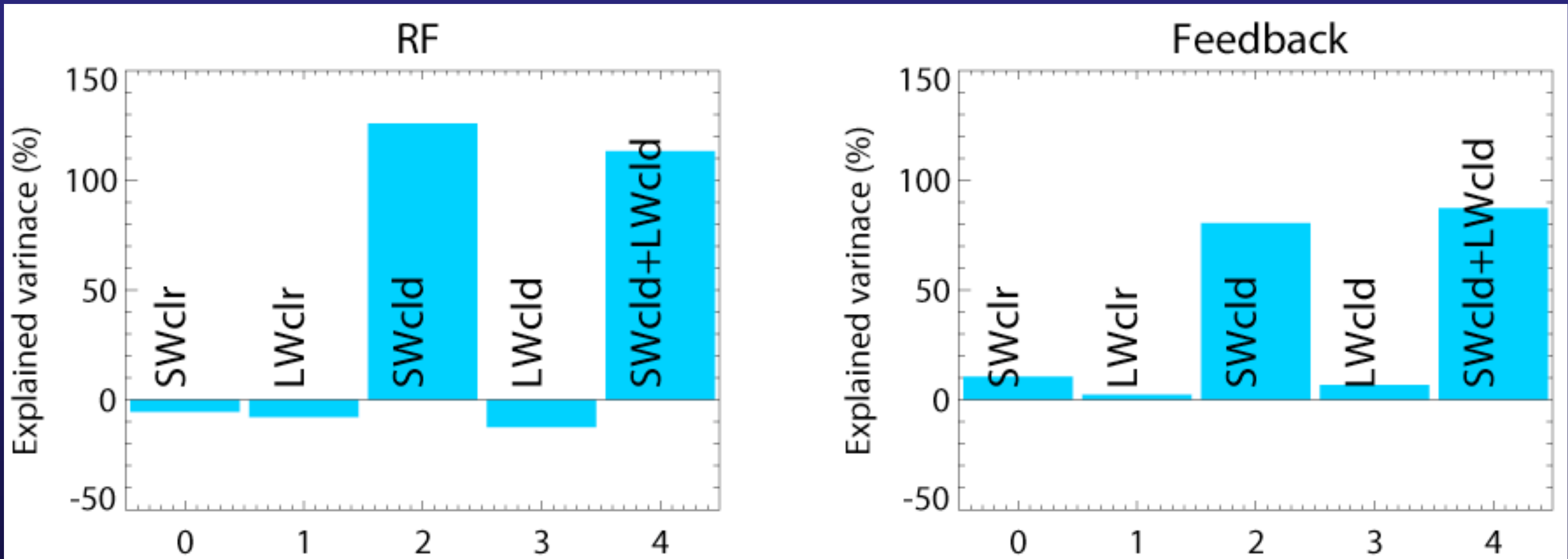
Global-mean SAT



Shiogama et al. (2011, submitted)

MIRoC5 PPE

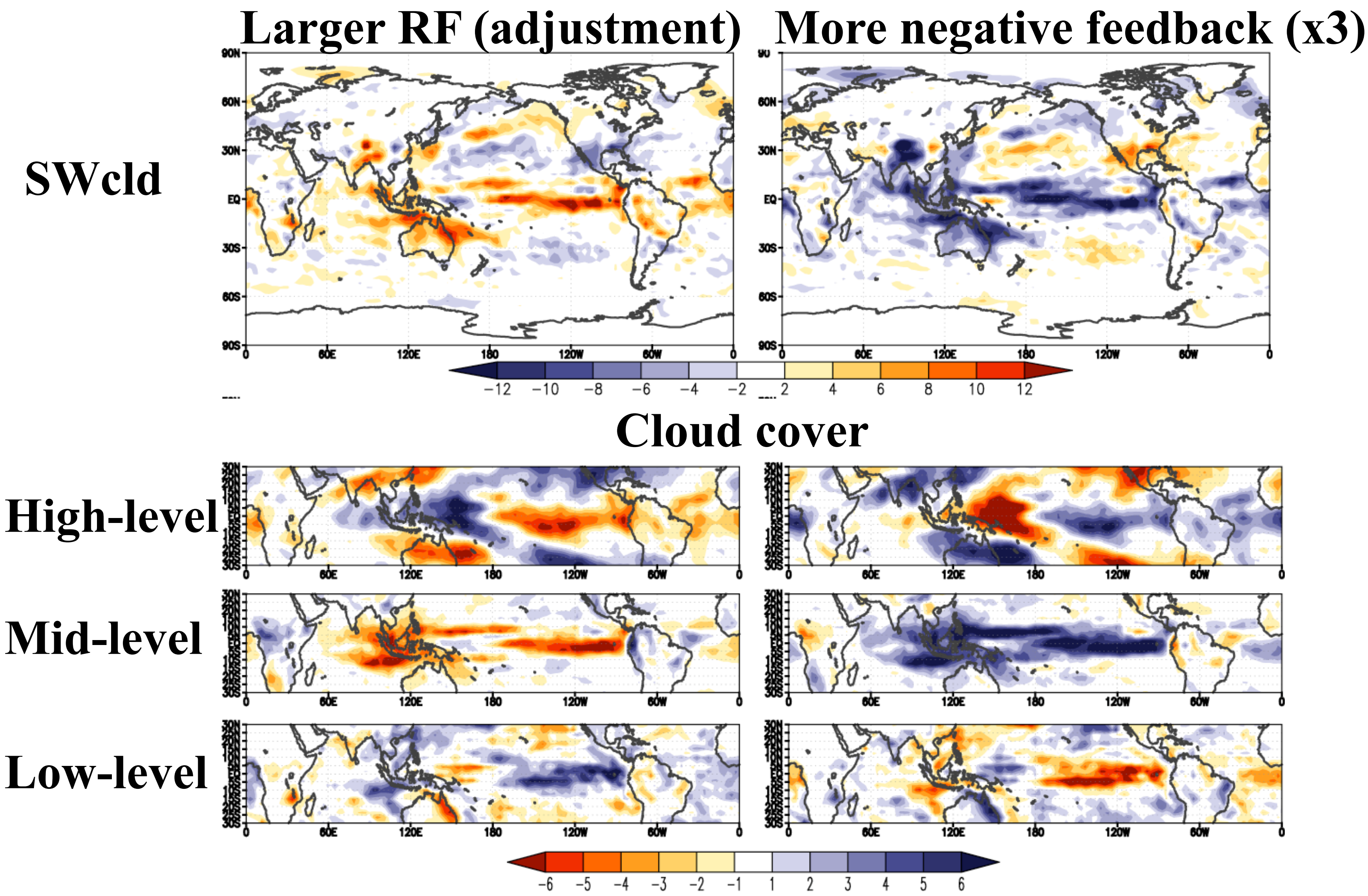
Inter-model variances of total forcing and feedback explained by each component



SWcld is the most important component for both the variances of forcing and feedback.

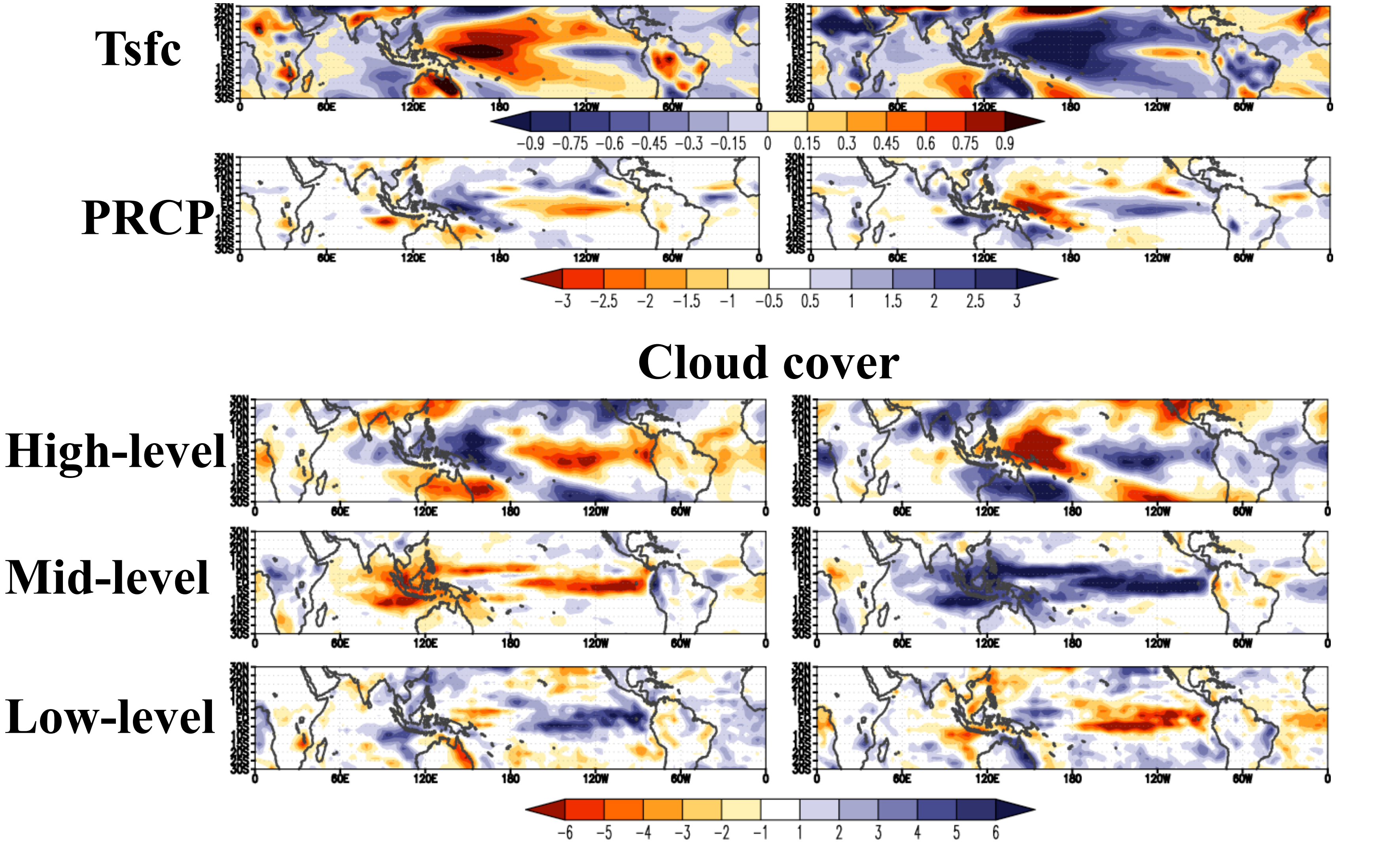
Shiogama et al. (2011, submitted)

Differences of composite:
(large positive SWcld RF, more negative SWcld FDB) minus
(small positive SWcld RF, less negative SWcld FDB)



Differences of composite:
(large positive SWcld RF, more negative SWcld FDB) minus
(small positive SWcld RF, less negative SWcld FDB)

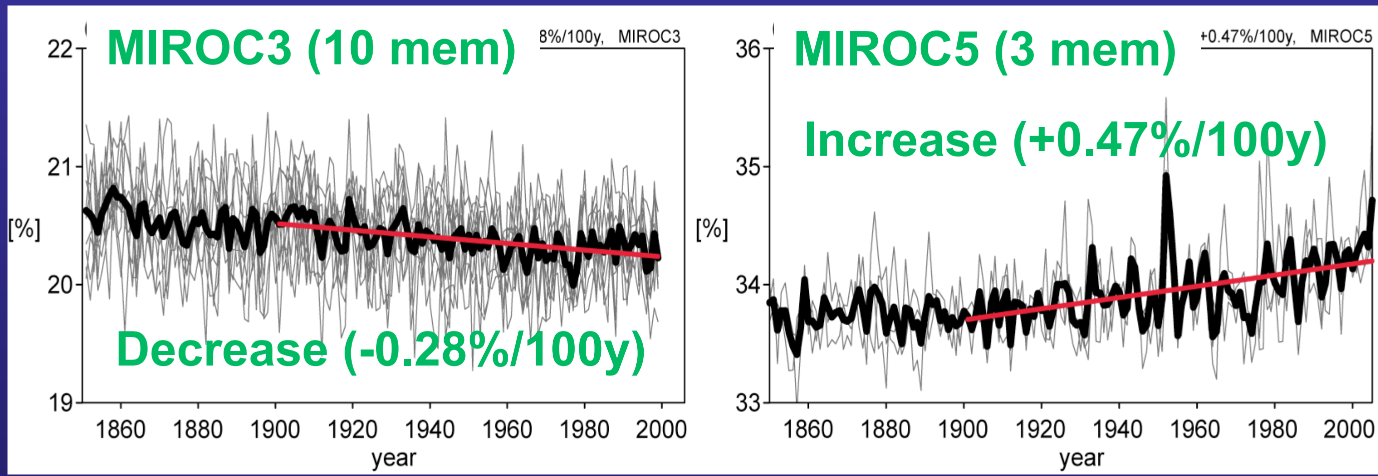
Larger RF (adjustment) **More negative feedback (x3)**



Implication to 20th century trends

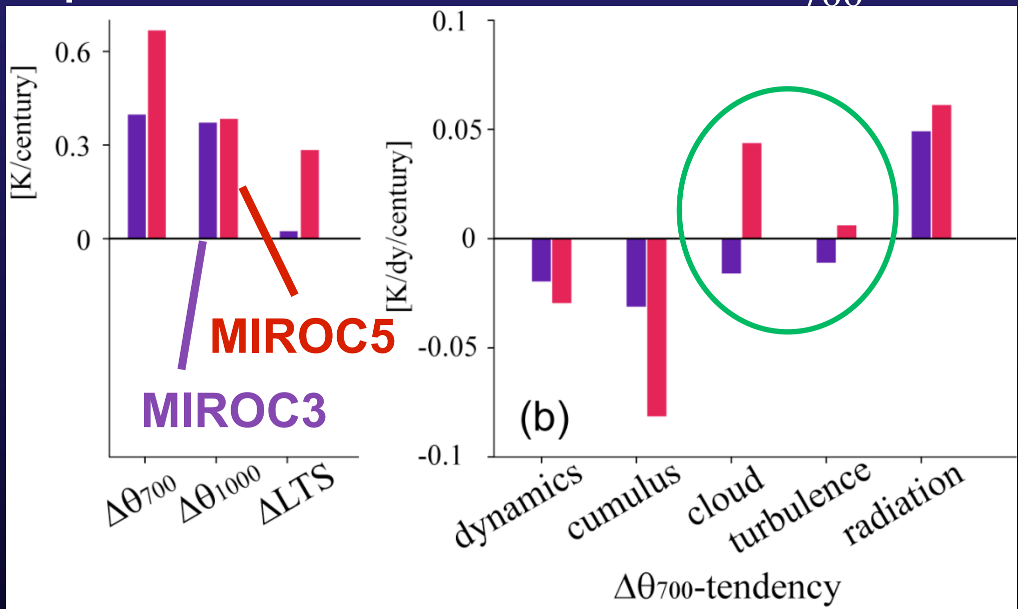
20C runs

Tropical
CI (30S-30N)



✓ Likely due to 'fast' response (but change is much slower)

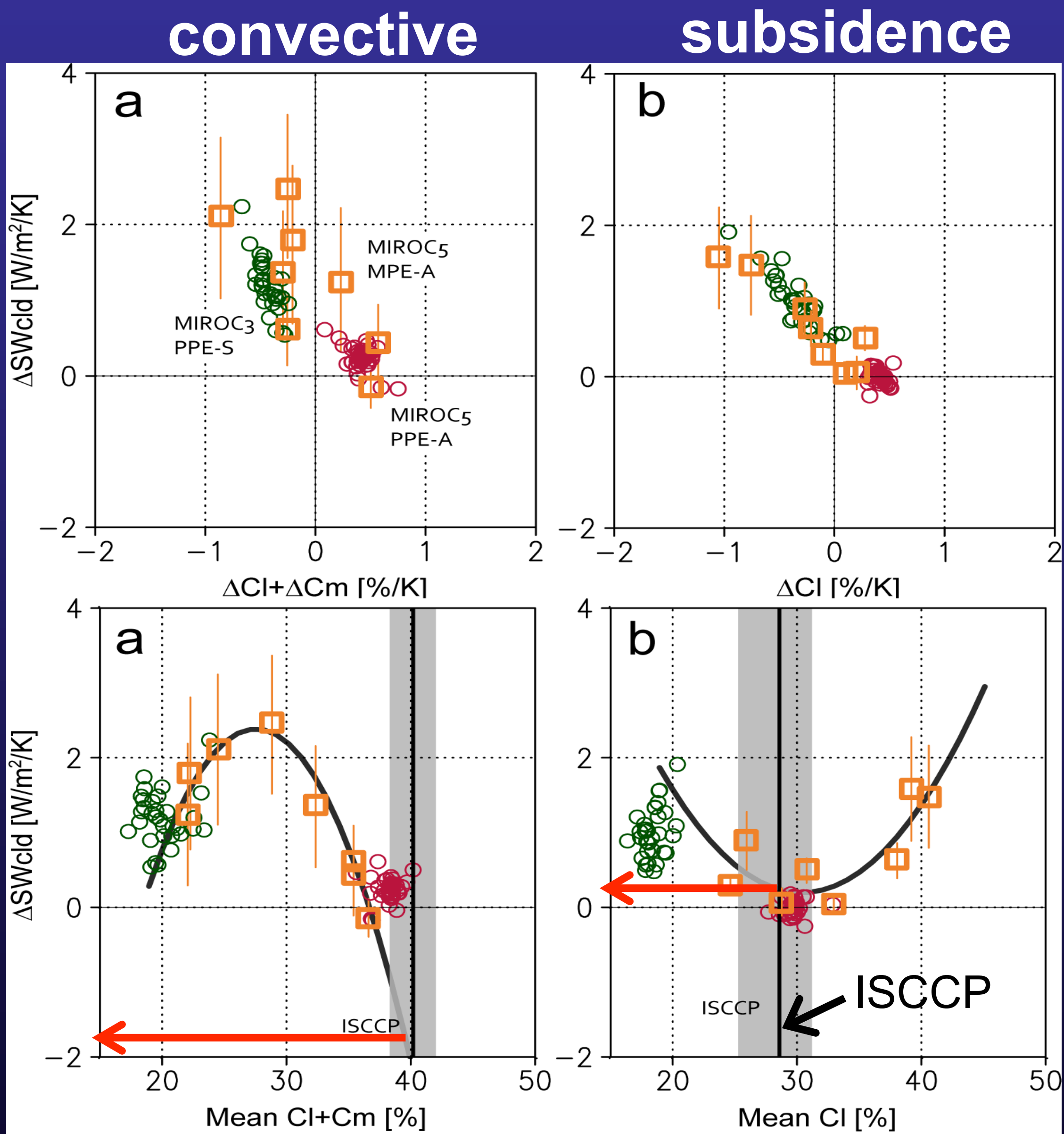
Tropical-mean trends in θ & θ_{700}-tendency



Diff. θ_{700} tendency due to cloud physics & turbulence is essential !

Watanabe et al. (2011, ASL)

Can we constrain the cloud feedback?



Approx linear relation in SWcld feedback vs cloud fraction changes

Nonlinear relation in SWcld feedback vs *mean* cloud fraction

→ can be used for constraining ΔSWcld?

Watanabe et al. (2011, submitted)