Multi-Parameter Multi-Physics Ensemble (MPMPE)

A New Approach Exploring the Uncertainties of Climate Sensitivity

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Shiogama et al. (2014) Atmospheric Science Letters

Introduction

Climate sensitivities (CSs) differ between GCMs.

- The range of CS was 2.1–4.4˚C for the CMIP3 models.
- The spread of CSs was mainly caused by feedback (FB) and radiative forcing (RF) uncertainties according to cloud changes

Two sources of uncertainties.

“Parametric uncertainty”

- due to different parameter value setting (tuning).

“Structural uncertainty”

- due to different physical parameterisation schemes

Parametric uncertainty

Perturbed-Physics Ensemble (PPE)

- Uncertain parameter values of a single GCM were swept.
- Results of PPE depend on GCMs used.

  - MIROC3 PPE: CS=4.5-9.6 ˚C (Annan et al. 2005)
  - MIROC5 PPE: CS=2.2-3.2 ˚C (Shiogama et al. 2012)

- Previous studies have compared only two PPEs.
- “Emergent constraints” from a PPE are not necessarily carried into other PPEs and MME (Yokohata et al. 2010, Klocke et al. 2011, Sanderson 2011).

Structural uncertainty

Multi-Model Ensemble (MME)

- GCMs developed by different modelling centres.

Multi-Physics Ensemble (MPE)

Gettelman et al. (2012), Watanabe et al. (2012)

- Single or multiple physics schemes were replaced between 2 versions of a GCM developed in the same modelling centre.

Results of MME and MPE can depend on parameter setting.

We have proposed a new approach to explore both the parametric and structural uncertainties of CS

Multi-Parameter Multi-Physics Ensemble (MPMPE)

- Watanabe et al. (2012) developed 8 MPE models by replacing schemes of cloud, convection and PBL of MIROC5 to those of MIROC3.
- We conducted 20 member PPEs using each of the 8 MPE models.
  - We randomly sampled values of 6 uncertain parameters using the Latin Hypercube method.
- We can compare PPEs of 8 GCMs!

The list of hybrid model names, and schemes of MIROC5 that were replaced by those of MIROC3.

Names	Cloud	Cumulus convection	Turbulence
CLD+CNV+VDF	MIROC3	MIROC3	MIROC3
CLD+VDF	MIROC3		MIROC3
CLD+CNV	MIROC3	MIROC3	
CNV+VDF		MIROC3	MIROC3
VDF			MIROC3
CNV		MIROC3	
CLD	MIROC3		
MIROC5A			

MIROC5←→MIROC3

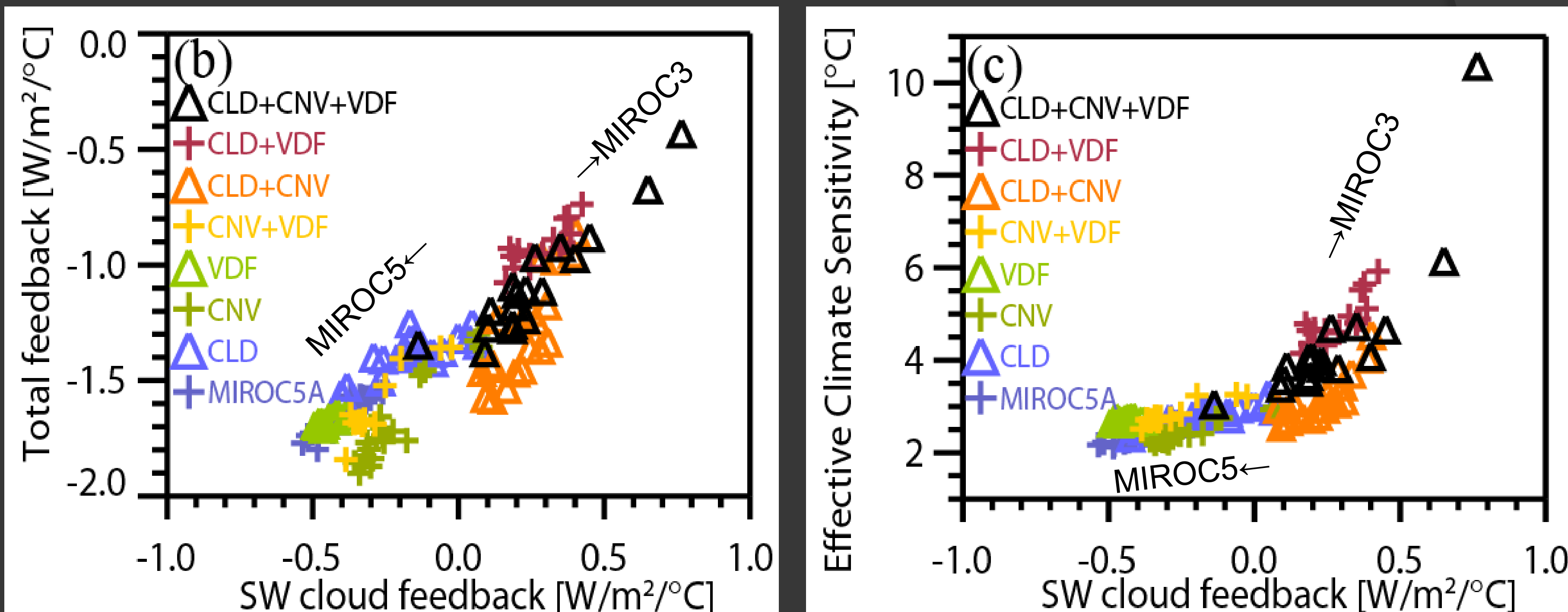
AGCM experiments

- *CTL*: AGCM runs (6yr) forced by 1XCO2 and the 10-year averaged SST and ICE from 1XCO2 runs of the standard MIROC5 CGCM.
- *CO2*: AGCM runs (6yr) forced by 4XCO2 and the 10-year averaged SST and ICE from 1XCO2 runs of the standard MIROC5 CGCM.
- *SST*: AGCM runs (6yr) forced by 1XCO2 and the year 11-20 period averaged SST and ICE from 4XCO2 runs of the standard MIROC5 CGCM.

- RF (for 2XCO2)= [R(CO2) − R(CTL)]/2
- FB = [R(SST) − R(CTL)]/[T(SST) − T(CTL)]
- ECS = − RF/FB

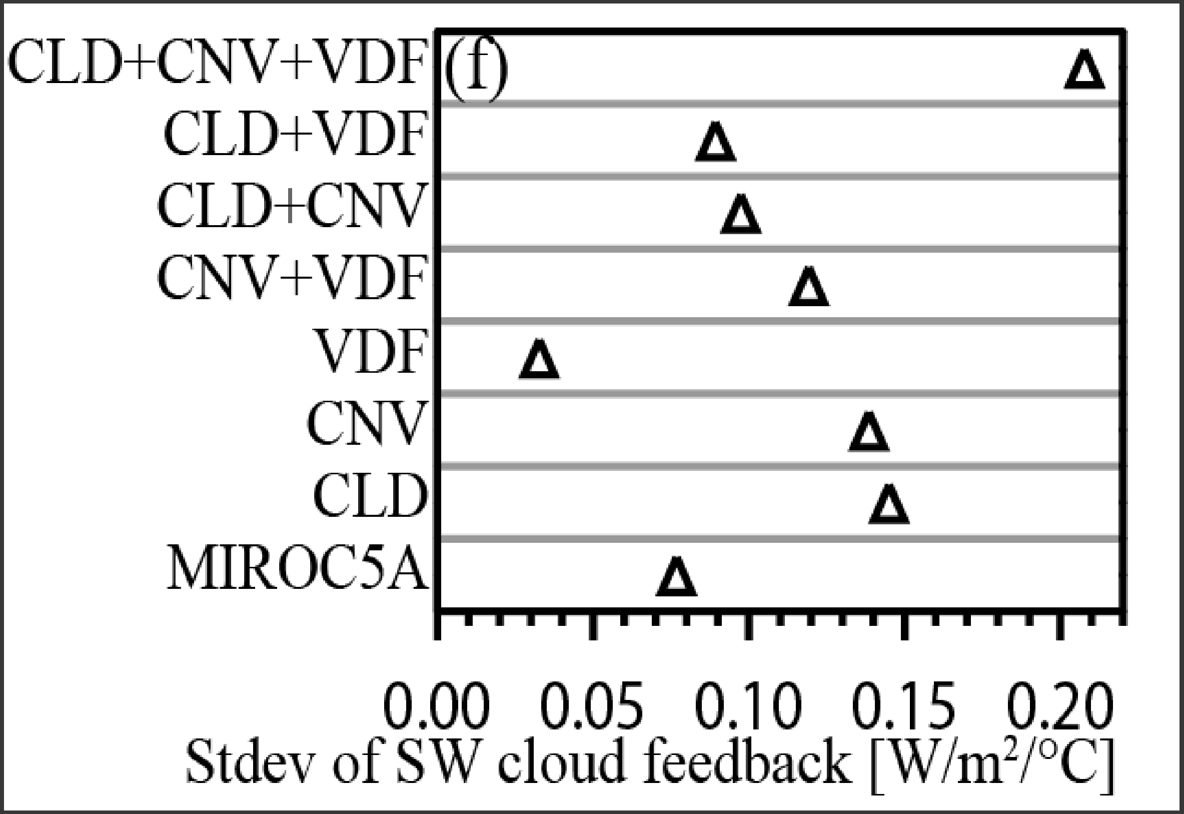
It should be noted that the ECS values calculated by our method can be taken as an estimate only.

SW cloud feedback relates well to the variations in the total feedback and ECS



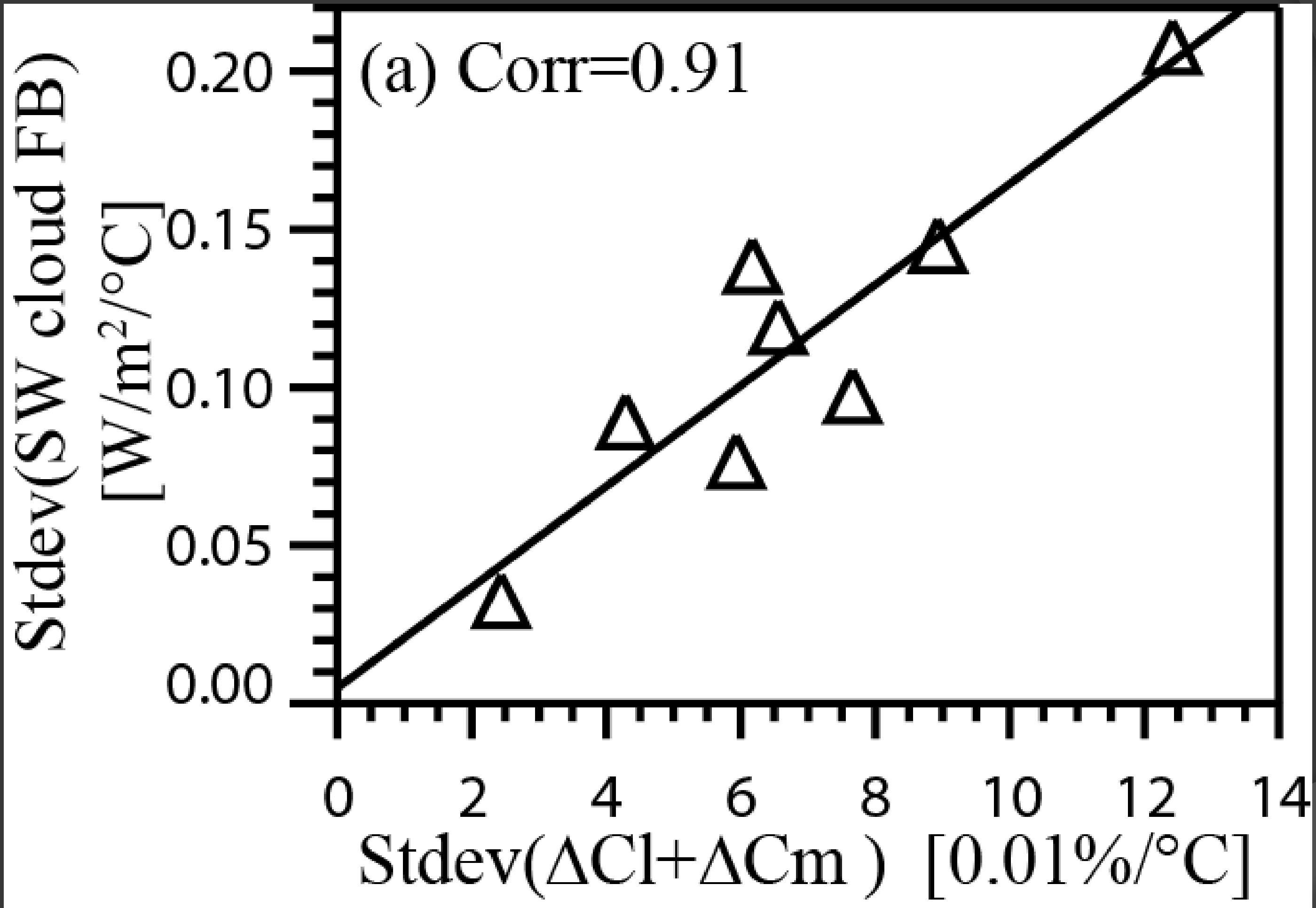
- MPMPE resulted in a wide range of CS, 2.1-10.4°C.
- SWcld FDBK relates well to ECS.
- As we move more closely towards MIROC3, we get higher ECS.

Standard deviation of SWcld across PPE members for a given MPE model [σ(SWcld)]



σ(SWcld) vary across the MPE models.
We investigate what factors control σ(SWcld).

σ(SWcld) relate well to σ(△Cl+△Cm)



△Cl = low-level cloud cover
△Cm = mid-level cloud cover

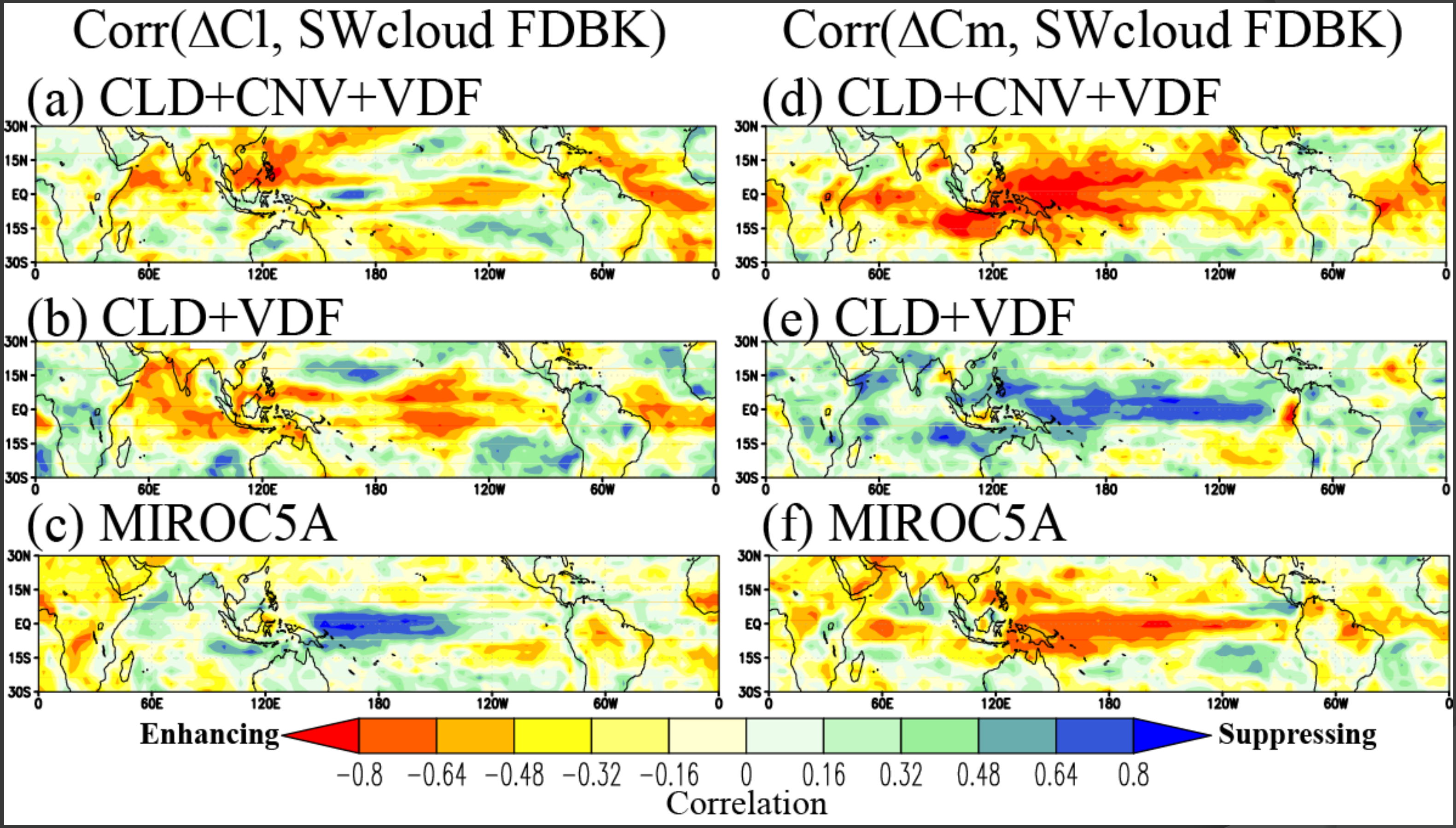
Correlation maps between global mean SWcld feedback and "△Cl or △Cm"

σ(SWcld)

large

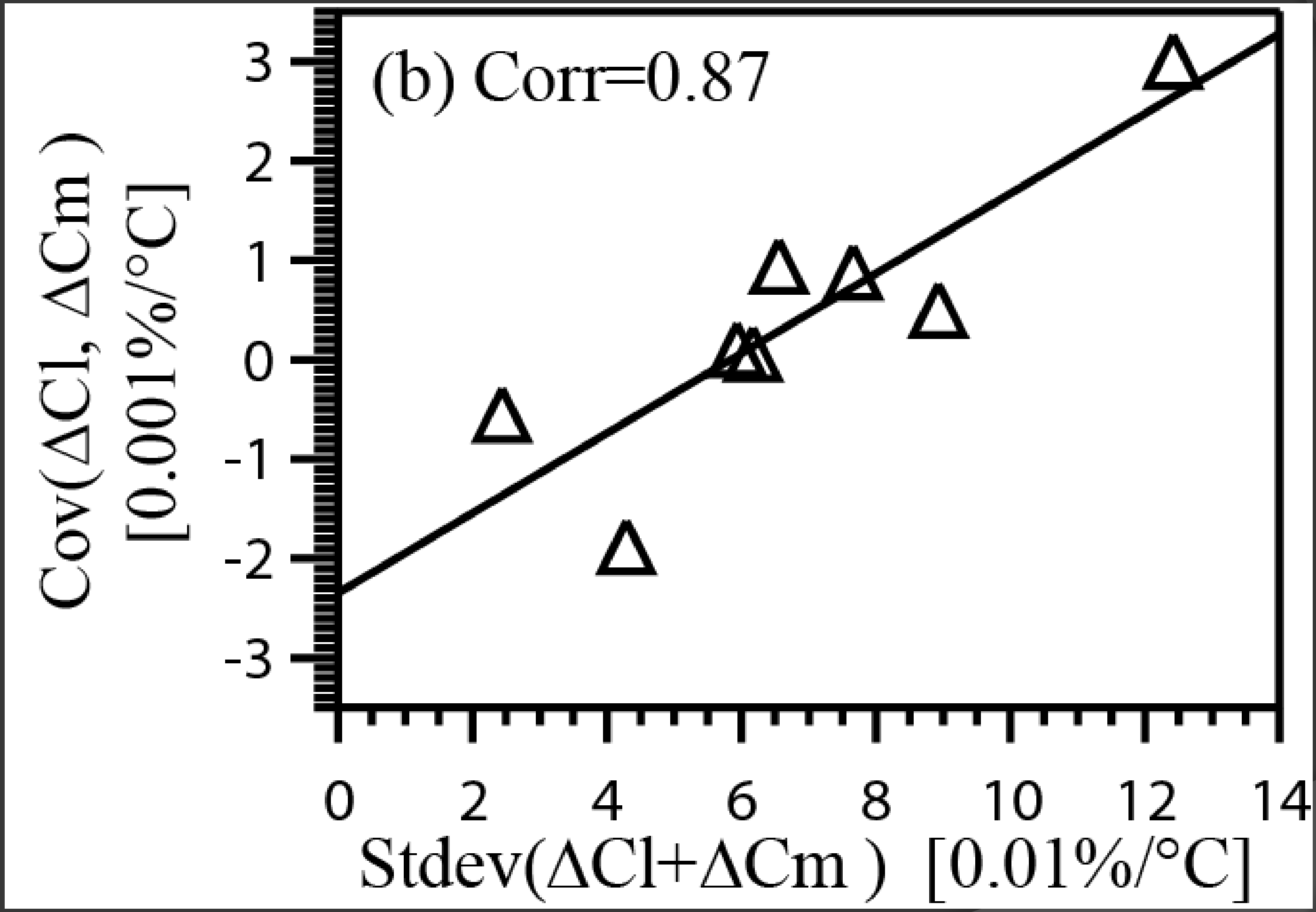
small

small



- Negative correlations indicate that changes in the cloud cover enhanced values of σ(SWcld) and vice versa.
- We have found discrepancies in the roles of clouds for the parametric spread of SWcld across the MPE models.
- Feedback mechanisms found in a PPE are not carried into other PPEs.

σ(△Cl+△Cm) are determined by covariance between △Cl and △Cm



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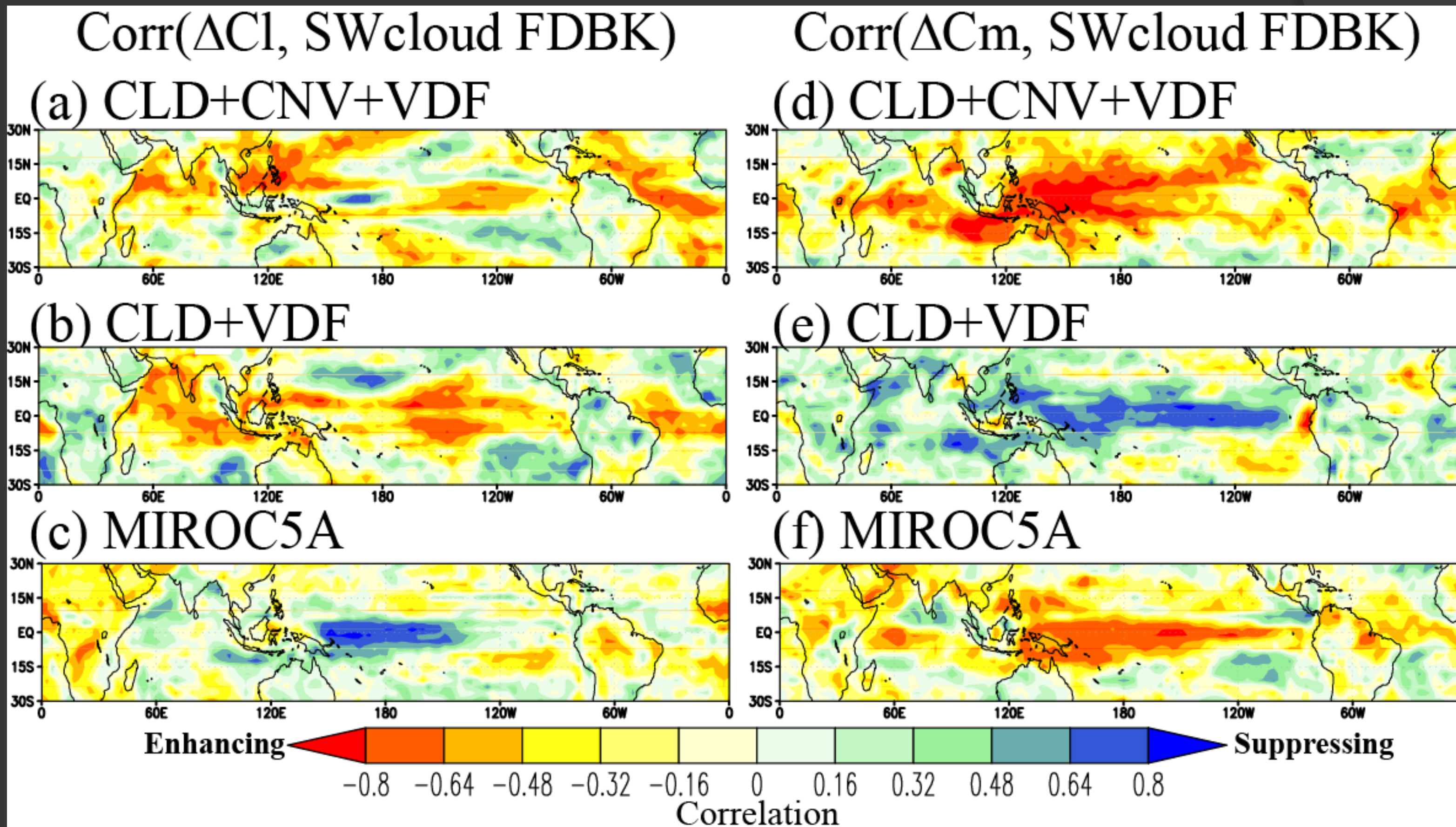
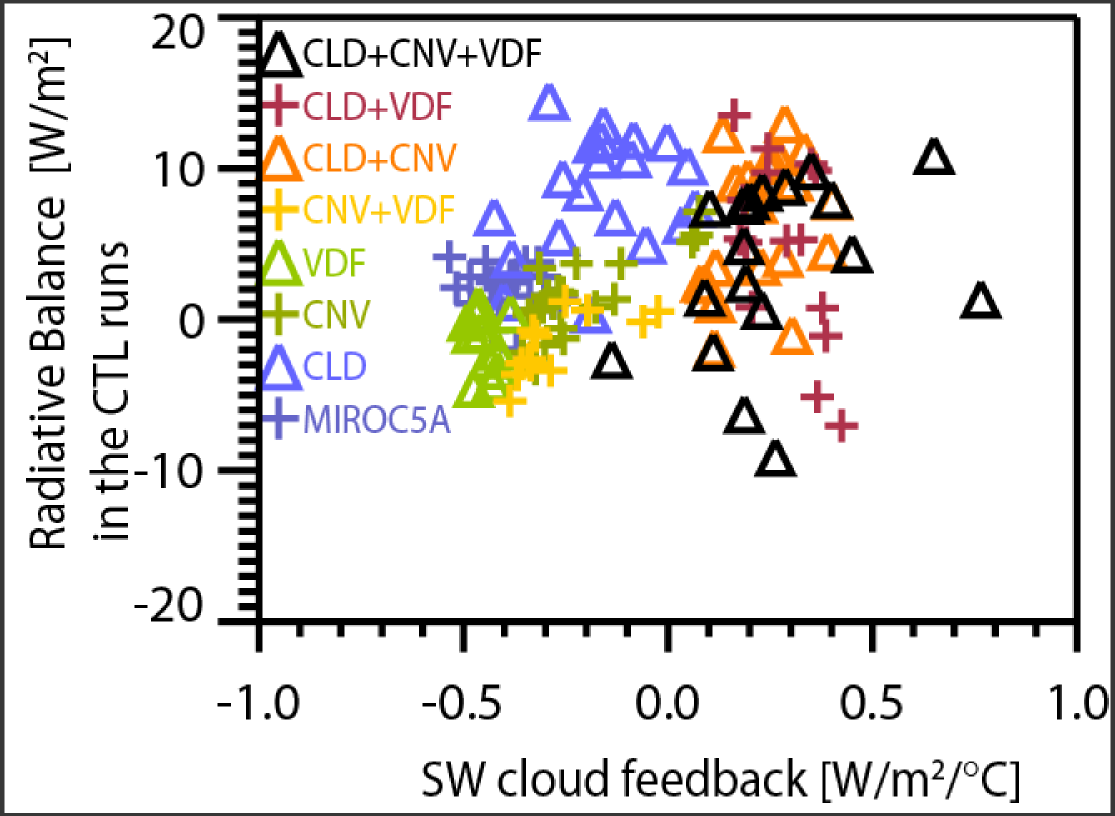


- When anomalies of △Cl and △Cm relative to the PPE averages have the same sign, σ(SWcld) is suggested to be enhanced.
- When △Cl and △Cm fluctuate in opposite directions, the PPE spreads of the SWcld are decreased.

Summary

- To explore both the parametric and structural uncertainties of ECS, we have proposed the new ensemble, MPMPE.
- MPMPE resulted in a wide range of CS, which was related to the shortwave cloud feedback (SWcld).
- Discrepancies existed in the roles of low- and mid-level clouds for the spread of SWcld between the MPE models.
- However we also found a SWcld control that is common to all our model structures.
- Coupling between low- and mid-level clouds controlled the differences in the parametric spread of SWcld across our MPE models.

Observational constraints of the uncertainty?



- We cannot use this simple metric to constrain the uncertainty of SWcld feedback.
- **Youichi Kamae will talk about more sophisticated 'emergent constraints' in the afternoon session.**

Table 1. A list of MPE model names, their ensemble sizes, and schemes of MIROC5 that were replaced by those of MIROC3.

Names	Ensemble sizes	Cloud	Cumulus convection	Turbulence
CLD+CNV+VDF	18	MIROC3	MIROC3	MIROC3
CLD+VDF	15	MIROC3		MIROC3
CLD+CNV	20	MIROC3	MIROC3	
CNV+VDF	12		MIROC3	MIROC3
VDF	11			MIROC3
CNV	20		MIROC3	
CLD	20	MIROC3		
MIROC5A	20			

Table 2. Lists of the perturbed physics parameters and their ranges.

MIROC5

Name	Category	Description	Min	Max
vicec	Cloud	Factor for ice falling speed [$m^{0.474}/s$]	25.0	40.0
b1_5	Cloud	Efficiency factor for liquid precipitation [m^3/kg]	0.07	0.11
wcbmax	Cumulus	Max. cumulus updraft velocity at cloud base [m/s]	0.70	2.80
clmd	Cumulus	Entrainment efficiency [ND]	0.40	0.60
faz1	Turbulence	Factor for PBL overshooting [ND]	1.00	3.00
alp1	Turbulence	Factor for length scale L_T [ND]	0.16	0.30

MIROC3

Name	Category	Description	Min	Max
prctau	Cloud	*e*-folding time for ice precipitation [s]	4.02×10^3	3.05×10^4
b1_3	Cloud	Efficiency factor for liquid precipitation [m^3 kg^{-1} s^{-1}]	6.77×10^{-3}	0.119
rhmcrt	Cumulus	Critical relative humidity for cumulus convection [ND]	0.683	0.893
elamin	Cumulus	Minimum entrainment factor of cumulus convection [m^{-1}]	0.00	5.46×10^{-4}
dfmmin	Turbulence	Minimum vertical diffusion coefficient [m^2 s^{-1}]	0.0785	0.158
aml0	Turbulence	Maximum mixing length [m]	150	600

Parametric uncertainty

Perturbed-Physics Ensemble (PPE)

- Uncertain parameter values of a single GCM were swept.
- The PPEs can provide information that is valuable for characterising the parametric sensitivities of single GCMs.
- However, the properties of a climate system (such as the relationships between changes in clouds in a warming climate and their biases in the present climate) found in a PPE are not necessarily carried into other MME models or into the PPEs of different models (Yokohata et al. 2010, Klocke et al. 2011, Sanderson 2011).
- The results of a PPE can be sensitive to the selection of the perturbed parameters, their ranges, and the parameter value sampling methods.

Structural uncertainty

Multi-Model Ensemble (MME)

- GCMs developed by different modelling centres
- Tracing the uncertainties of the climate simulations to particular differences in the physics scheme structures is difficult.
- Particular parameter value sets.

Multi-Physics Ensemble (MPE)

- Single or multiple physics schemes were replaced between 2 versions of a GCM developed in the same modelling centre.
- Easier to trace uncertainties
- The results depend on the base models.
- Particular parameter value sets.

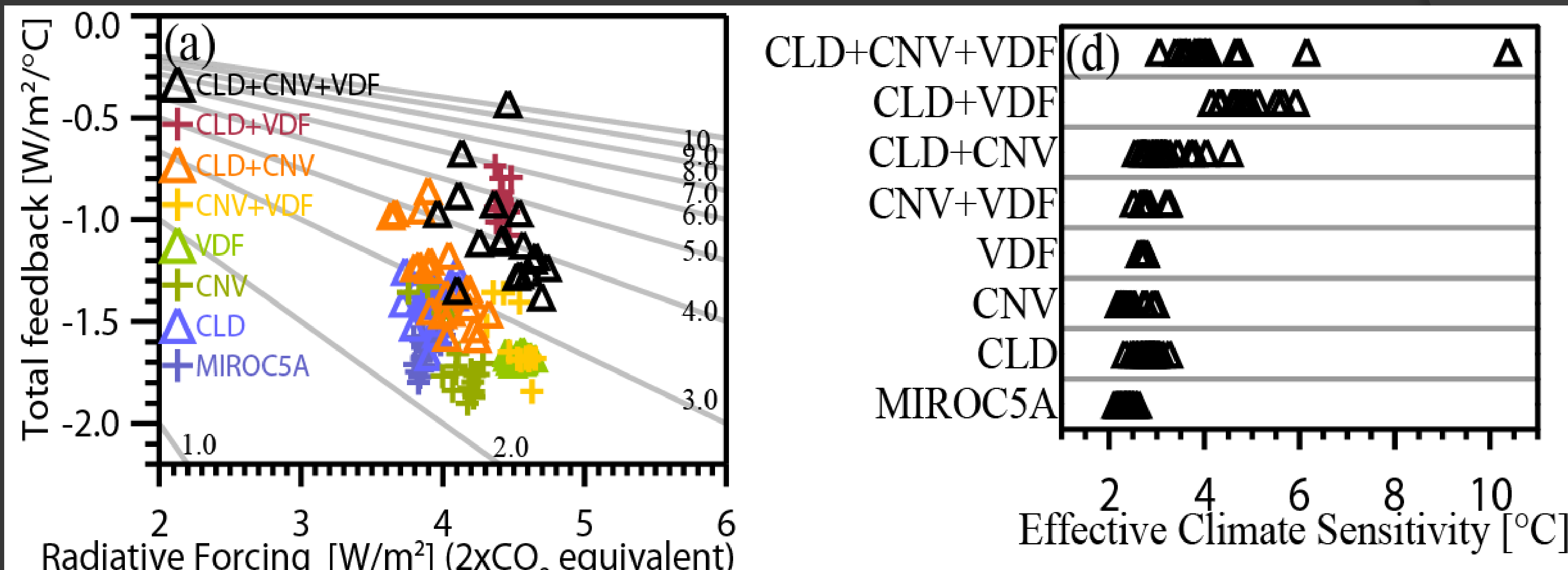
A new approach to explore both the parametric and structural uncertainties of CS

Multi-Parameter Multi-Physics Ensemble (MPMPE)

- We conducted PPEs with a common sampling strategy using each of the 8 MPE models (Watanabe et al., 2012).
- Schemes of cloud, convection and PBL of MIROC5 were replaced to those of MIROC3.
- 20 PPEs X 8 MPEs
- We randomly sampled values of 6 uncertain parameters using the Latin Hypercube method.

- Are there any common properties across all our PPEs?

Radiative forcing, Feedback and ECS



MPMPE resulted in a wide range of CS, 2.1-10.4°C.

SW cloud feedback relates well to the variations in the total feedback and ECS