

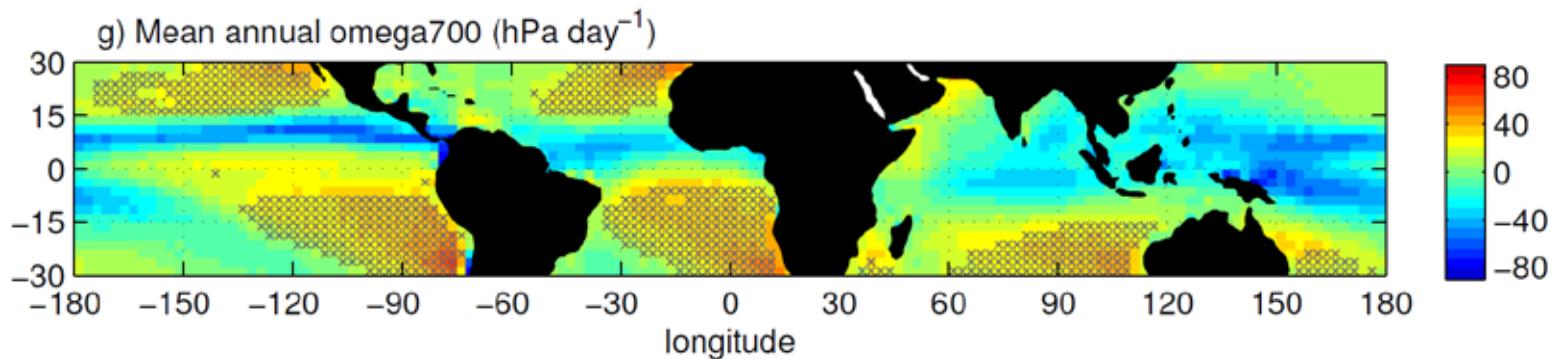
Constraining MBL Cloud Feedback with Interannual Cloud-Meteorology Relationships

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CFMIP Meeting on Cloud Processes and Cloud Feedbacks
June 8, 2015

Some Analysis Details

- Ensemble mean meteorology from CFSR, ERA-Interim, JRA-55, MERRA
- SW cloud radiative effect from CERES (2000-2012) and ISCCP FD (1984-1999)
- 19 CMIP5 models with different atmospheric cores
- 30°N-30°S subsidence regime



A Model for MBL Cloudiness in the Subsidence Regime

$$SW = f(SST, EIS, RH_{700}, SSTadv, \omega_{700})$$

SW = shortwave cloud radiative effect

Meteorological Parameters

- sea surface temperature (SST)
- estimated inversion strength (EIS)
- 700 hPa relative humidity (RH_{700})
- 700 hPa pressure vertical velocity (w_{700})
- advection over the SST gradient ($SSTadv = -\nabla \cdot \tilde{N}SST$)

Multi-linear Regression Model

Leading order Taylor expansion:

$$\begin{aligned}\Delta SW = & \frac{\partial SW}{\partial SST} \Delta SST + \frac{\partial SW}{\partial EIS} \Delta EIS + \frac{\partial SW}{\partial RH_{700}} \Delta RH_{700} \\ & + \frac{\partial SW}{\partial SSTadv} \Delta SSTadv + \frac{\partial SW}{\partial \omega_{700}} \Delta \omega_{700}\end{aligned}$$

- derived from detrended monthly grid box anomalies

Multi-linear Regression Model

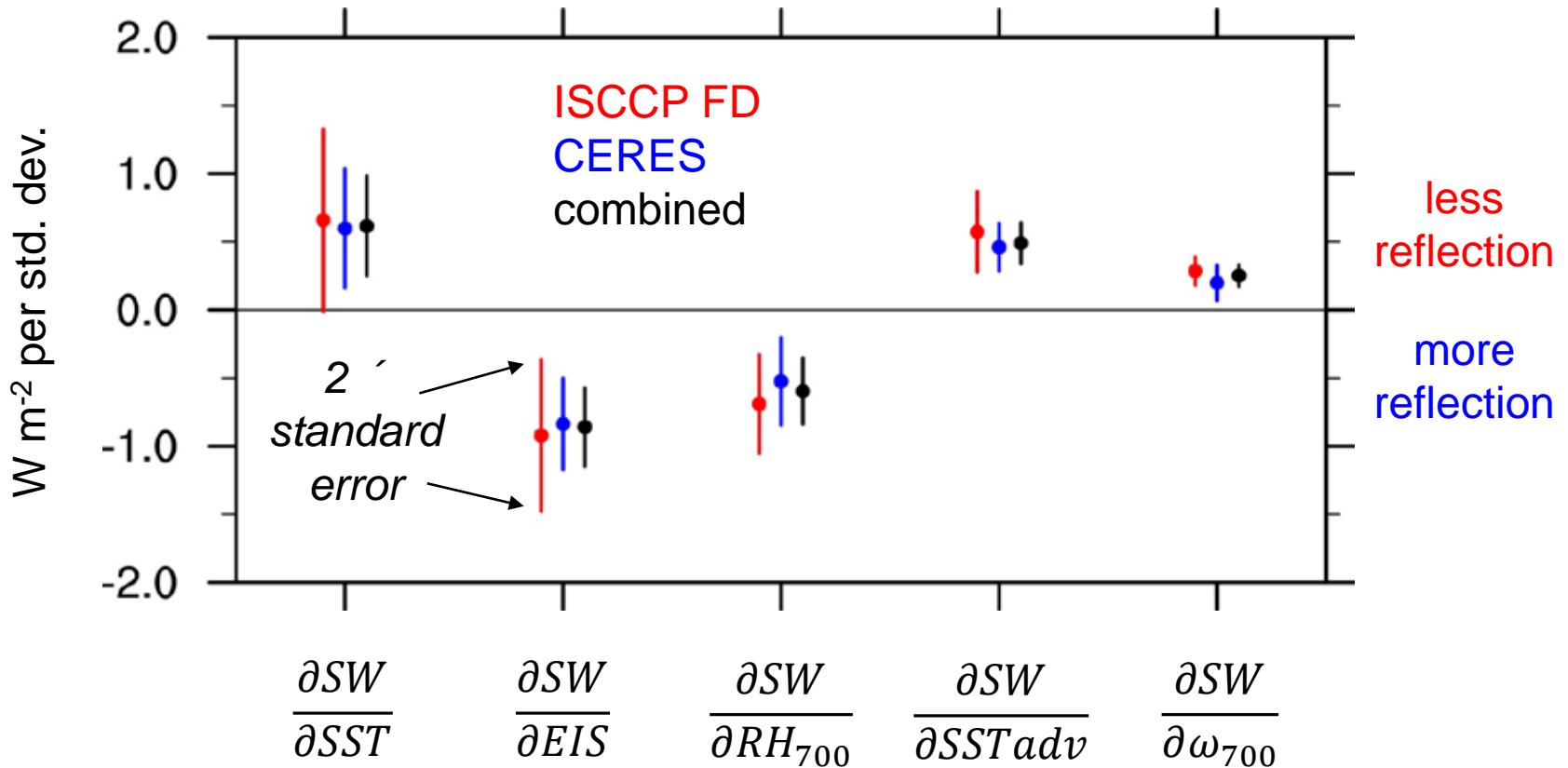
Leading order Taylor expansion:

$$\begin{aligned}\Delta SW = & \frac{\partial SW}{\partial SST} \Delta SST + \frac{\partial SW}{\partial EIS} \Delta EIS + \frac{\partial SW}{\partial RH_{700}} \Delta RH_{700} \\ & + \frac{\partial SW}{\partial SSTadv} \Delta SSTadv + \frac{\partial SW}{\partial w_{700}} \Delta w_{700}\end{aligned}$$

Correlation between monthly anomalies

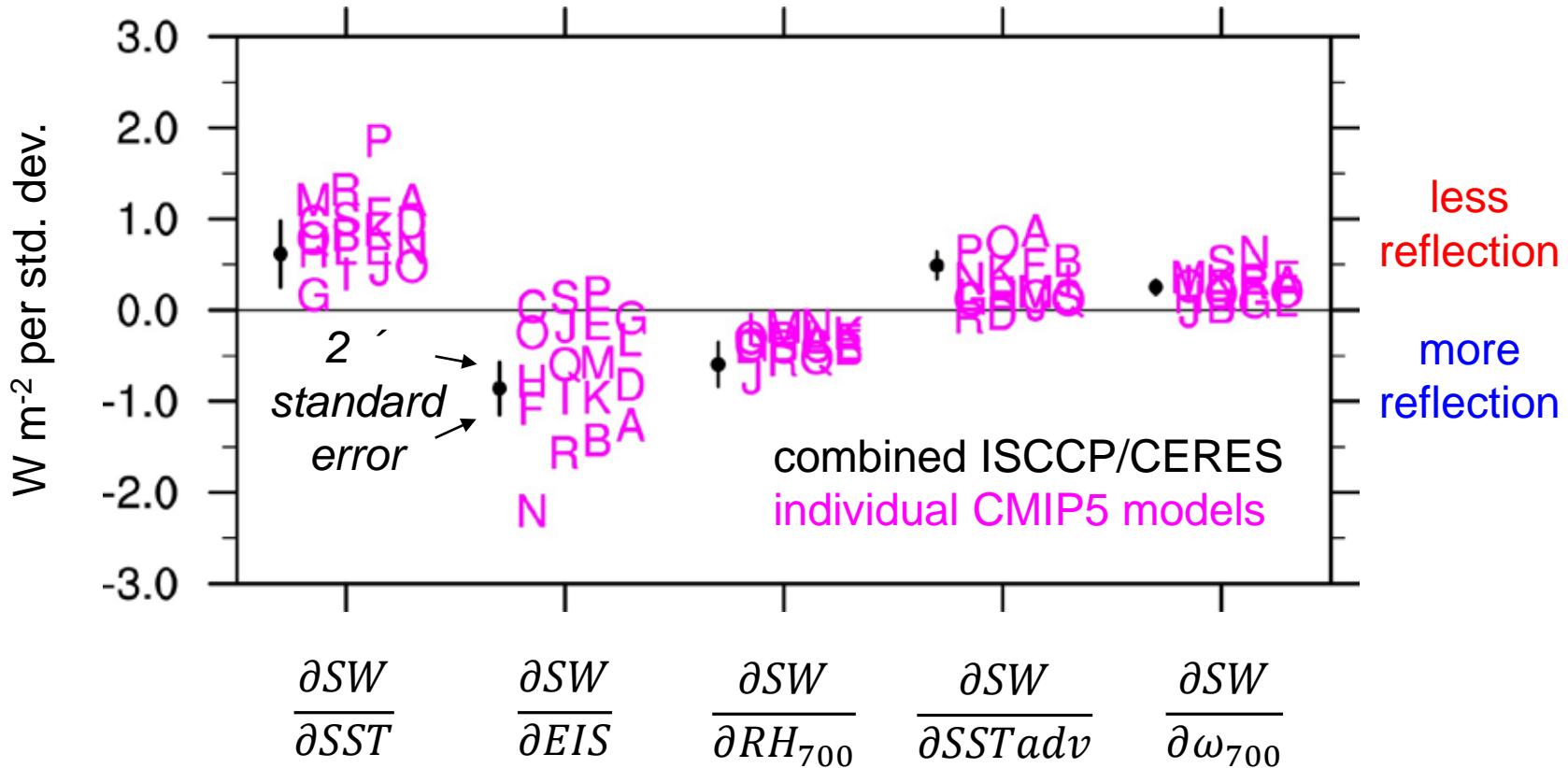
	EIS	RH ₇₀₀	SSTadv	w ₇₀₀
SST	- 0.52	+0.22	+0.28	- 0.19
EIS		- 0.50	- 0.14	+0.14
RH ₇₀₀			+0.20	- 0.43
SSTadv				- 0.29

Spatial Mean Observed Coefficients



coefficients scaled by standard deviation of monthly anomalies

Observed and CMIP5 Coefficients



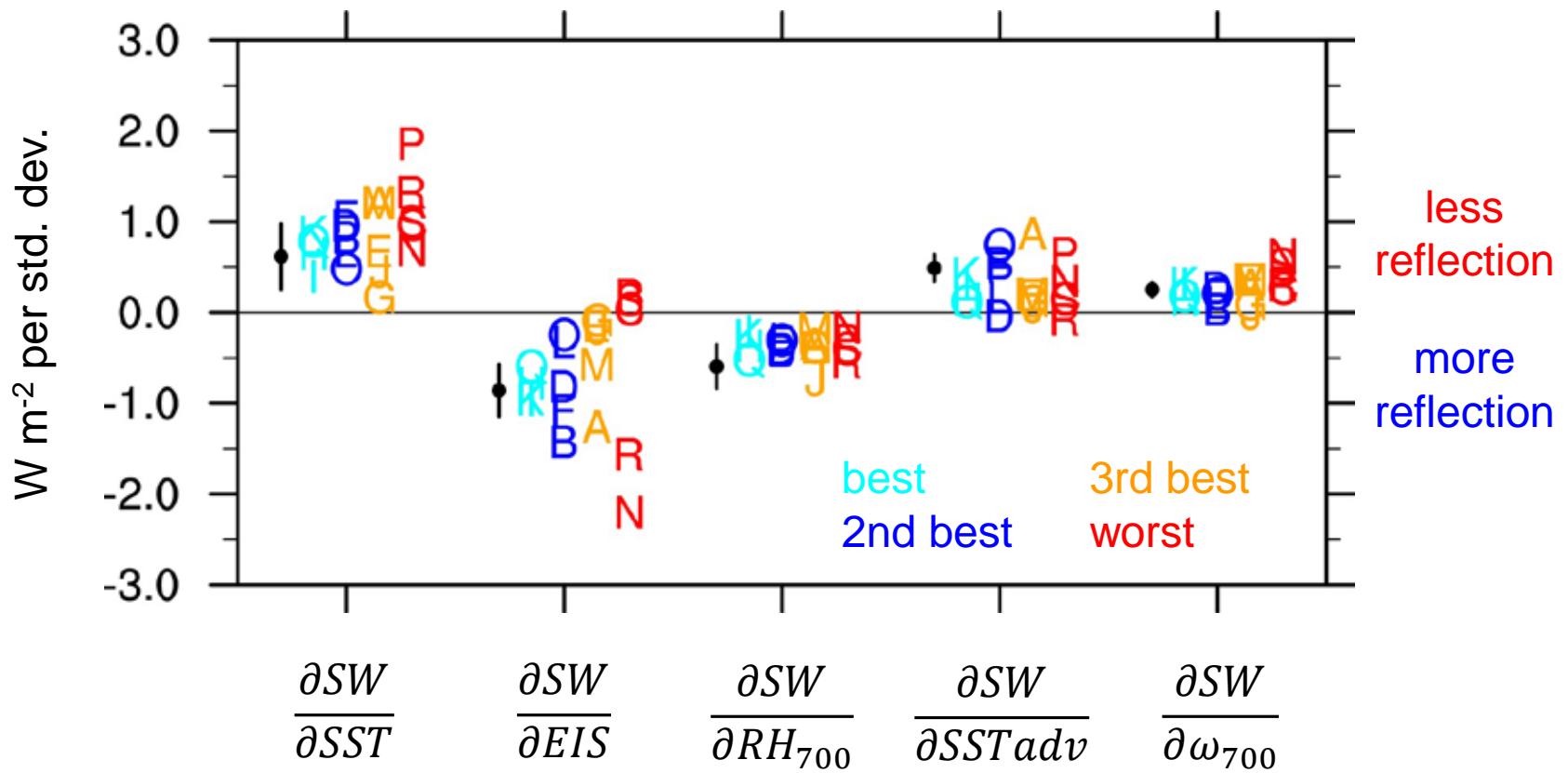
coefficients scaled by standard deviation of monthly anomalies

CMIP5 MBL Cloud Evaluation Metric

$$RMSdiff = \left(\sum_{i=1}^5 \left(\frac{\partial SW}{\partial X_i} \Big|_{CMIP} - \frac{\partial SW}{\partial X_i} \Big|_{obs} \right)^2 / 5 \right)^{1/2}$$

CMIP5 MBL Cloud Evaluation Metric

$$RMSdiff = \left(\sum_{i=1}^5 \left(\frac{\partial SW}{\partial X_i} \Big|_{CMIP} - \frac{\partial SW}{\partial X_i} \Big|_{obs} \right)^2 / 5 \right)^{1/2}$$



Prediction of Multidecadal Cloud Trends

Not shown for reasons of time (in extra slides)

- Multi-linear regression model successfully predicts 1984-2009 trends in ISCCP and PATMOS-x cloudiness in subtropical stratocumulus regions
- Individual contribution by trend in each meteorological parameter is identified

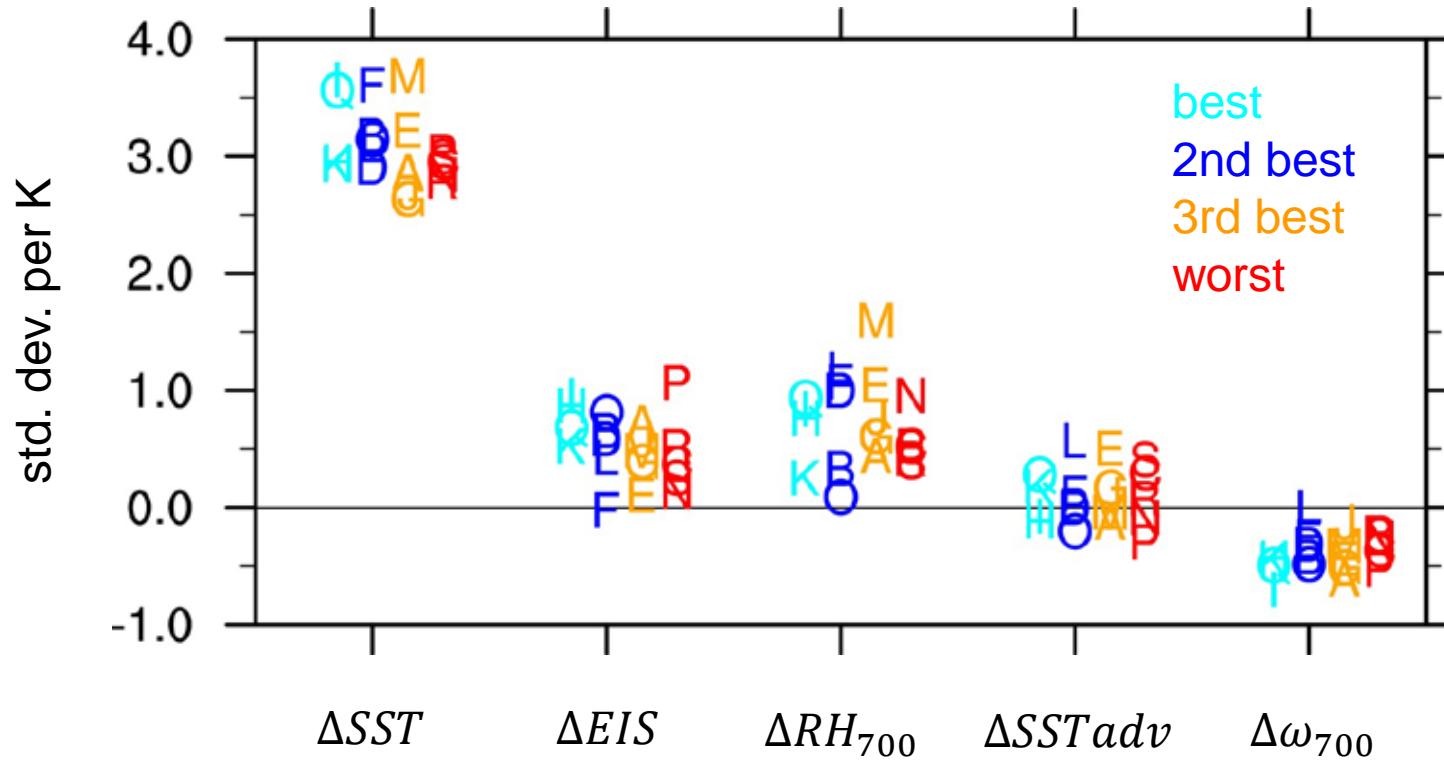
Prediction of 4xCO₂ SW Cloud Radiative Effect Change

$$\begin{aligned}\Delta SW = & \frac{\partial SW}{\partial SST} \Delta SST + \frac{\partial SW}{\partial EIS} \Delta EIS + \frac{\partial SW}{\partial RH_{700}} \Delta RH_{700} \\ & + \frac{\partial SW}{\partial SSTadv} \Delta SSTadv + \frac{\partial SW}{\partial \omega_{700}} \Delta \omega_{700}\end{aligned}$$

DX = difference between average of first 20 years and last 20 years
from abrupt 4xCO₂ simulations (“slow response”)

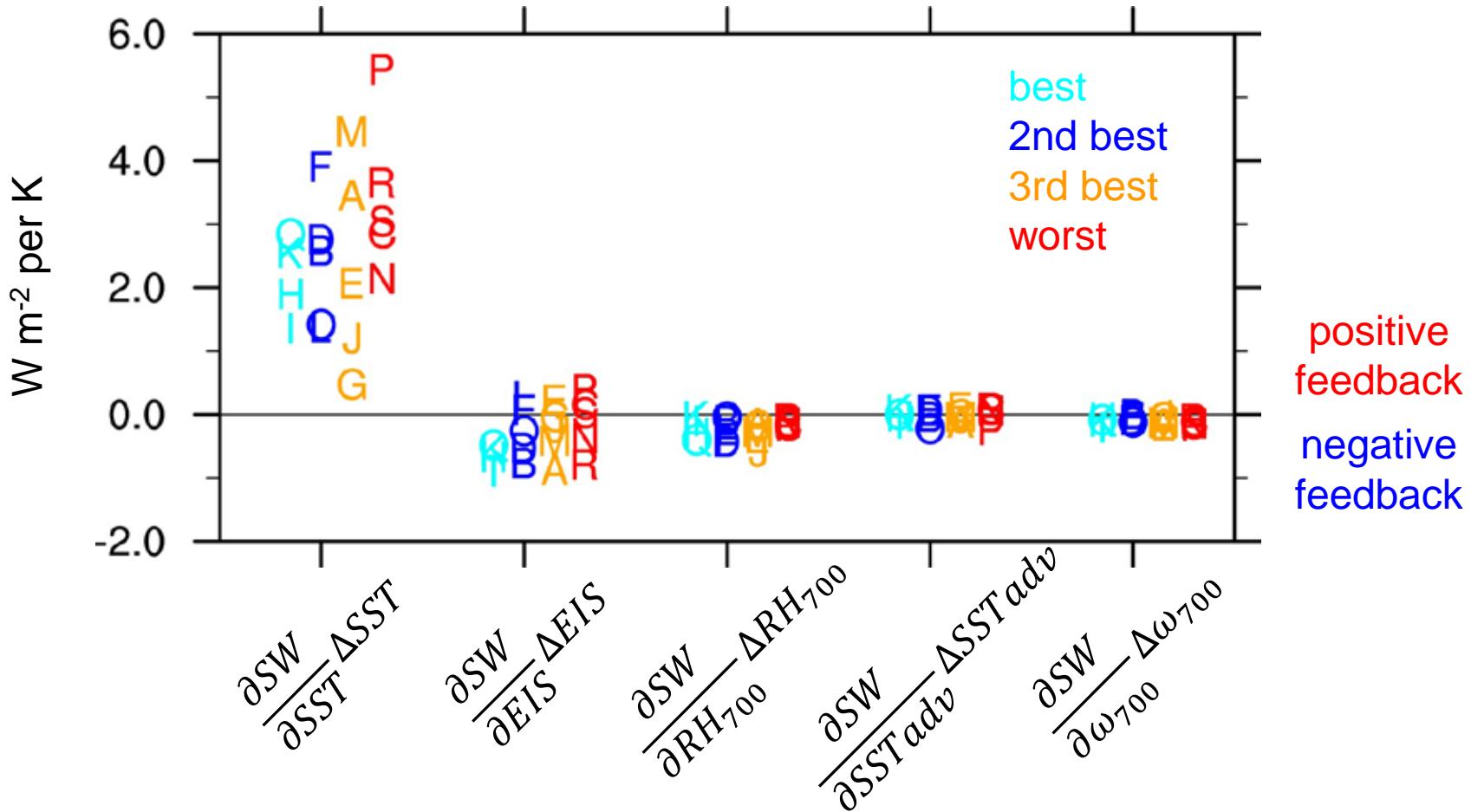
*Can change in meteorological parameters be used
to predict change in SW cloud radiative effect?*

CMIP5 4xCO₂ Meteorological Changes

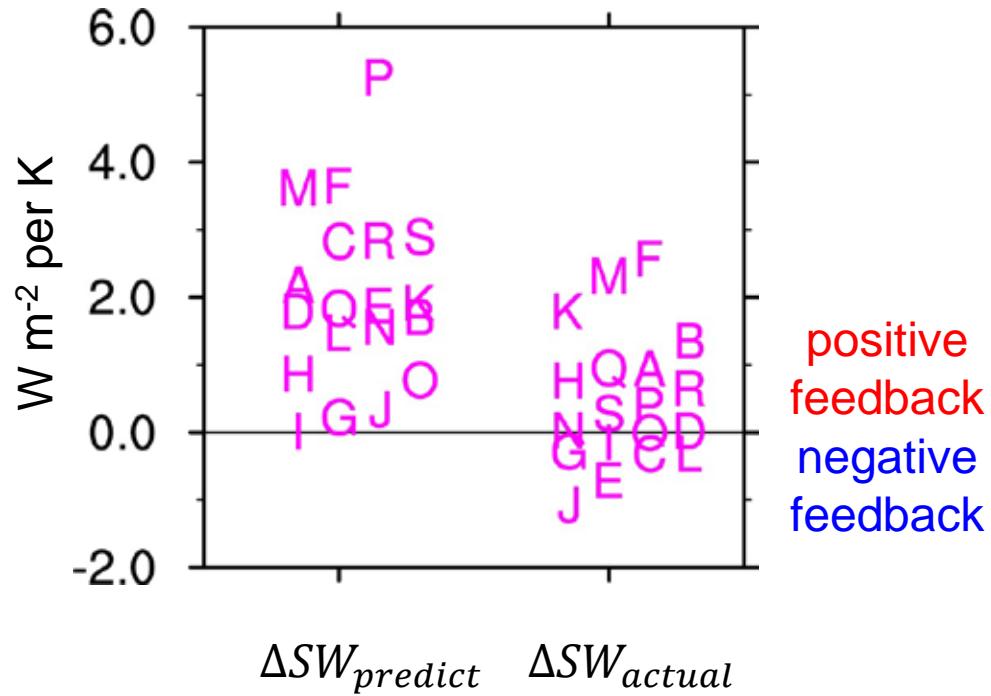


meteorological changes in units of standard deviation of monthly anomalies and scaled by global mean temperature change

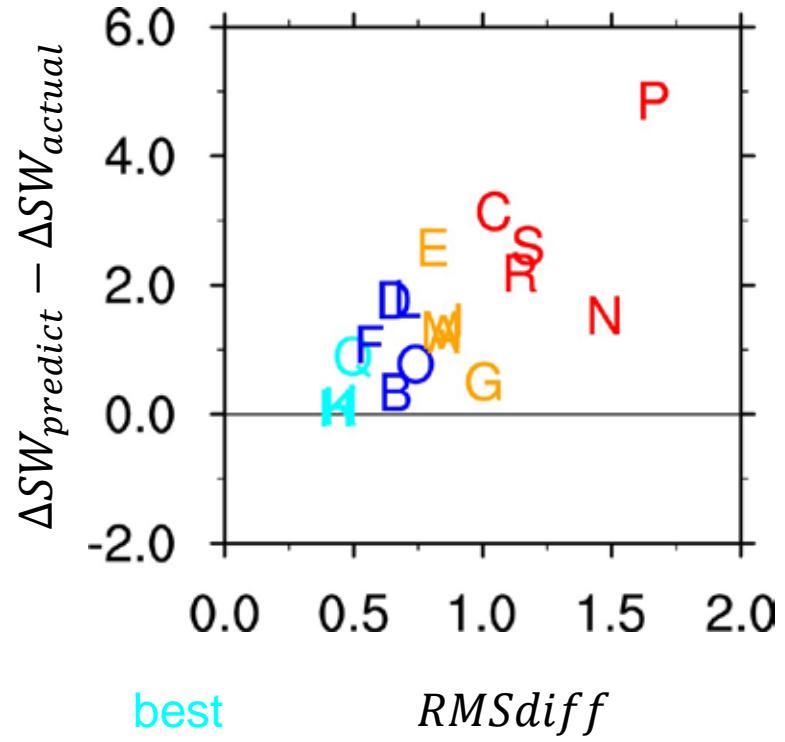
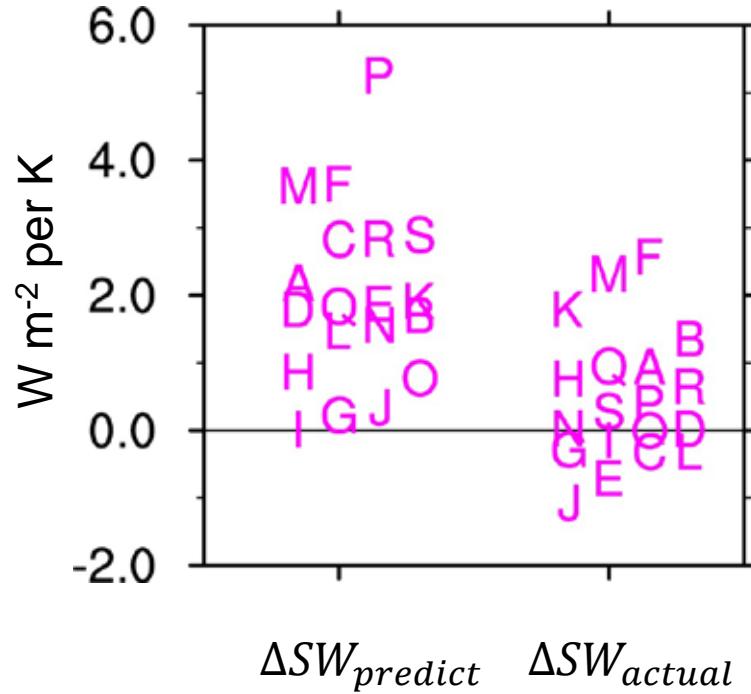
CMIP5 SW Cloud Feedback Components



Predicted and Actual CMIP5 SW Cloud Feedback

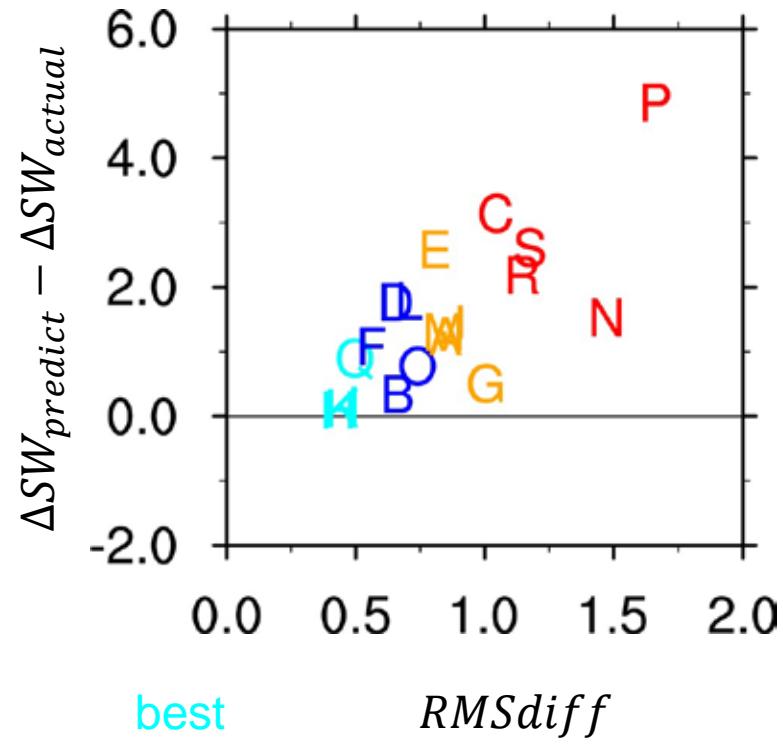
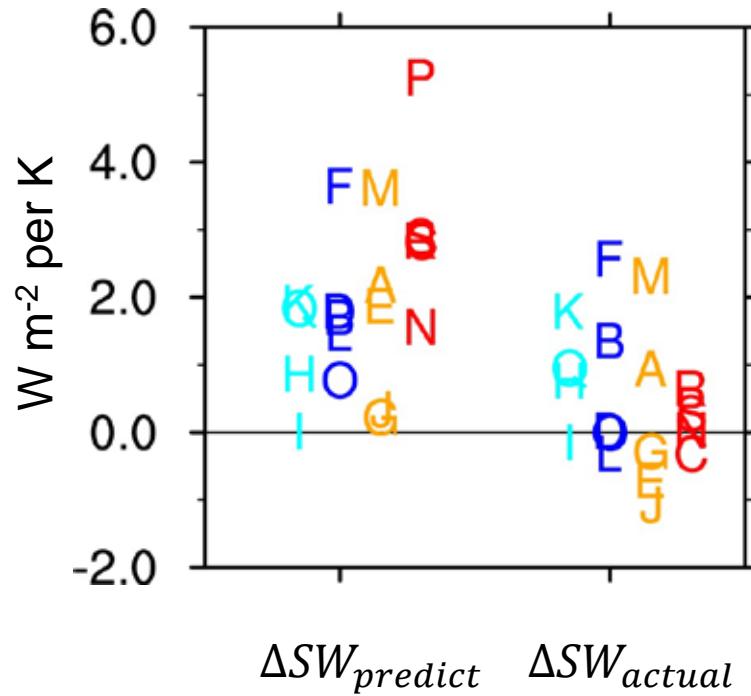


Predicted and Actual CMIP5 SW Cloud Feedback



best
2nd best
3rd best
worst

Predicted and Actual CMIP5 SW Cloud Feedback



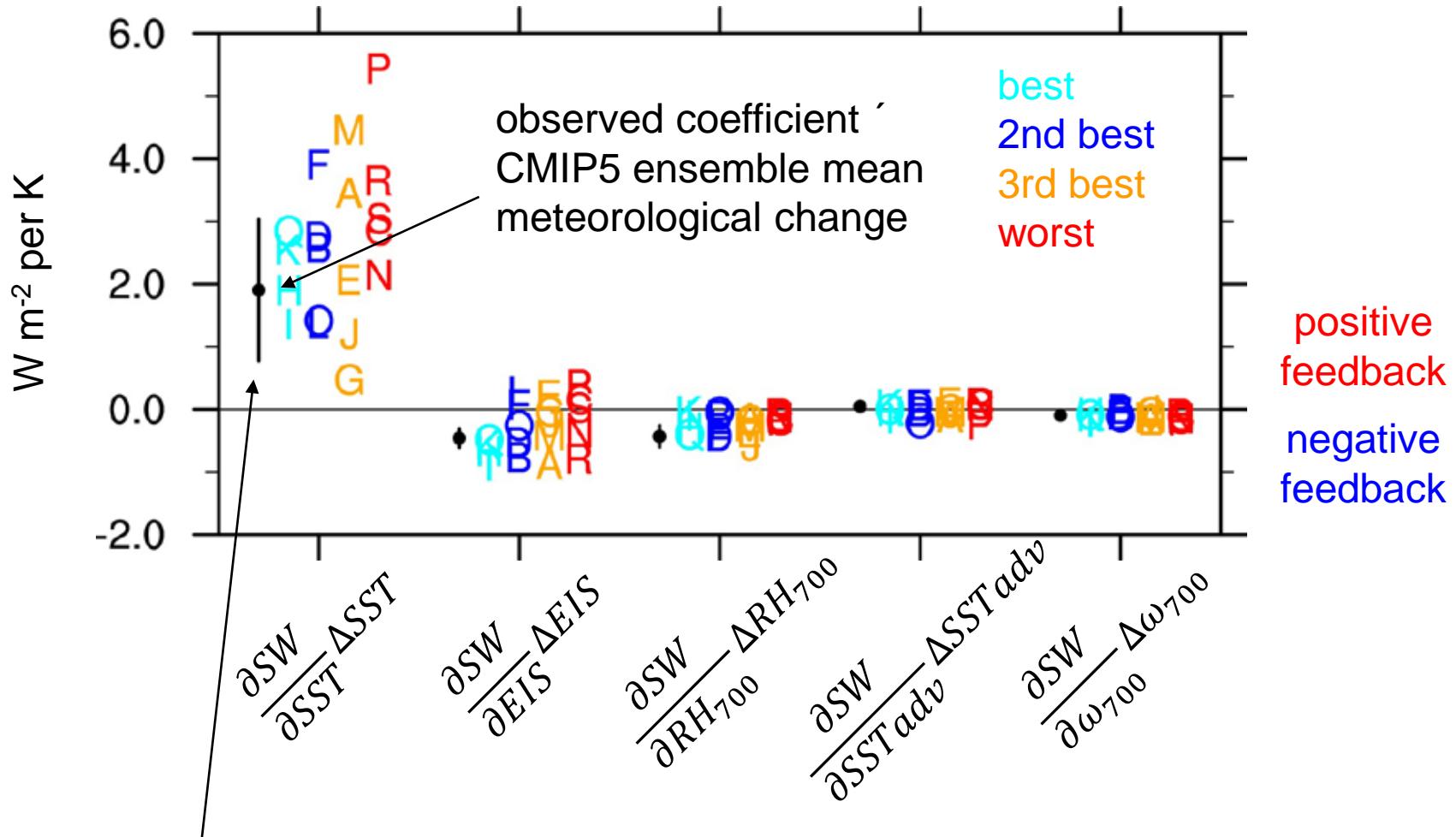
best
2nd best
3rd best
worst

SW Cloud Feedback From Observed Coefficients

$$\begin{aligned}\Delta SW = & \left. \frac{\partial SW}{\partial SST} \right|_{obs} \Delta SST_{ens} + \left. \frac{\partial SW}{\partial EIS} \right|_{obs} \Delta EIS_{ens} + \left. \frac{\partial SW}{\partial RH_{700}} \right|_{obs} \Delta RH_{700\,ens} \\ & + \left. \frac{\partial SW}{\partial SSTadv} \right|_{obs} \Delta SSTadv_{ens} + \left. \frac{\partial SW}{\partial \omega_{700}} \right|_{obs} \Delta \omega_{700\,ens}\end{aligned}$$

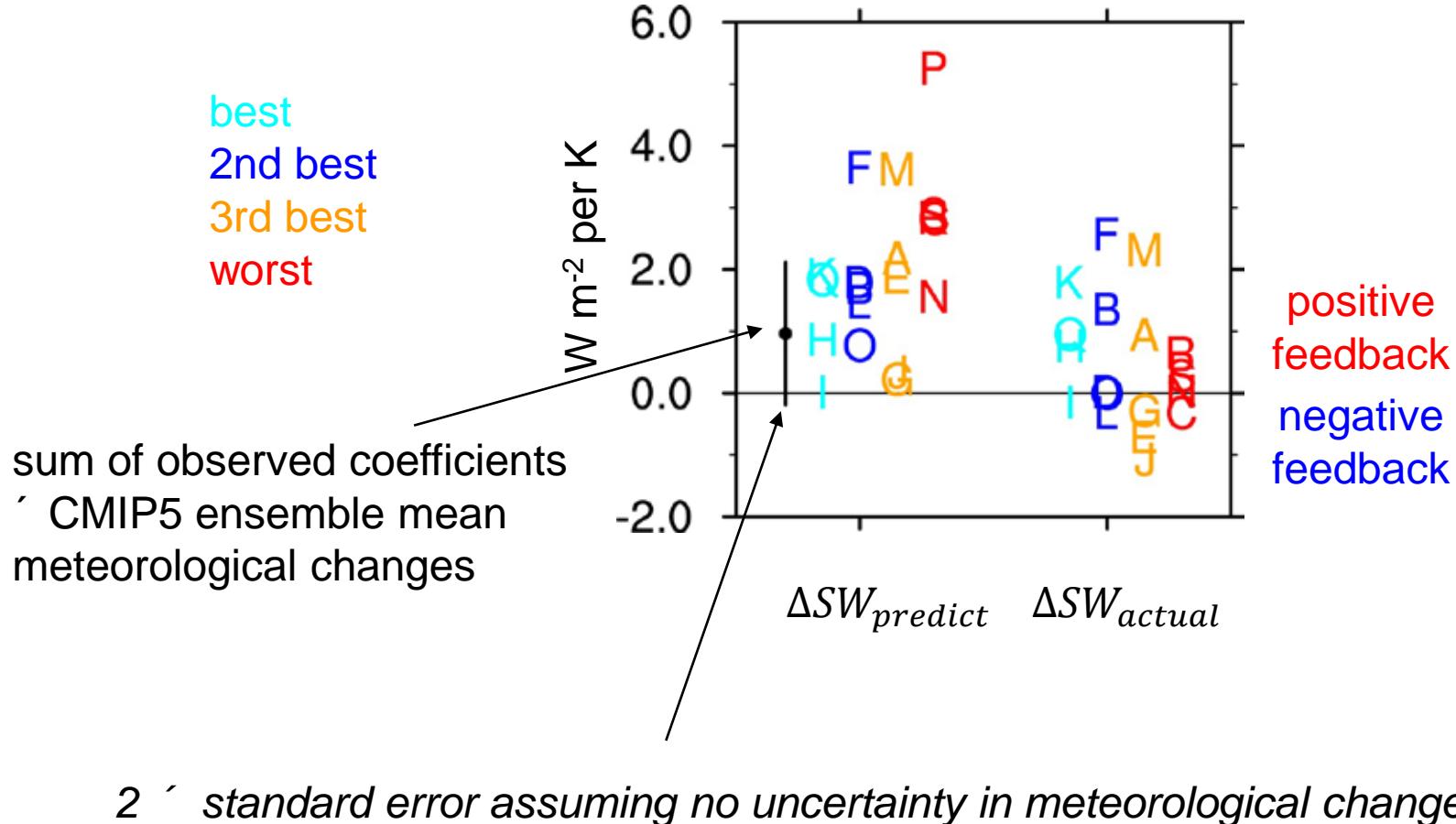
Multiply observed coefficients by the
CMIP5 ensemble mean change in meteorological parameter

SW Feedback Components with Observed Coefficients

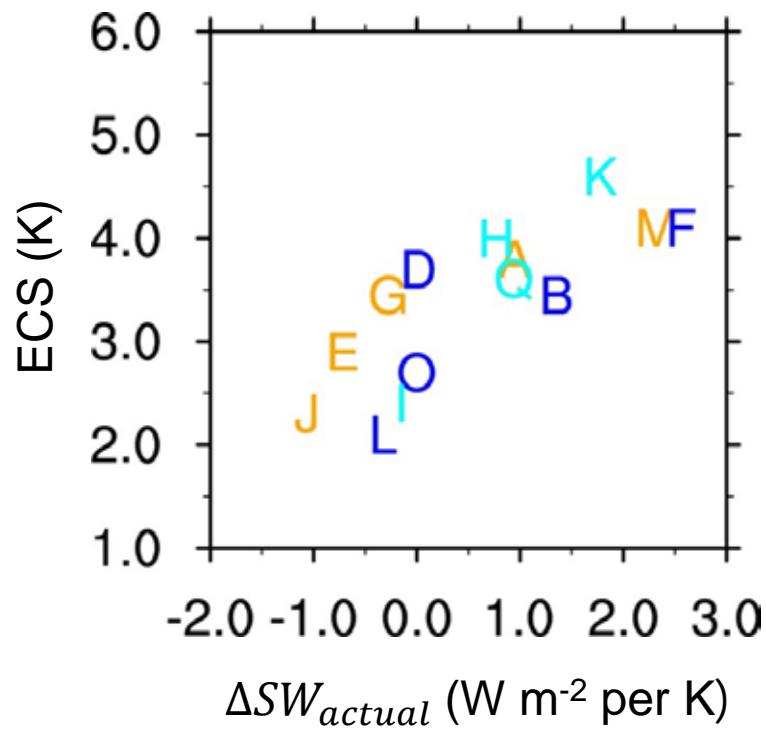


2σ standard error assuming no uncertainty in meteorological change

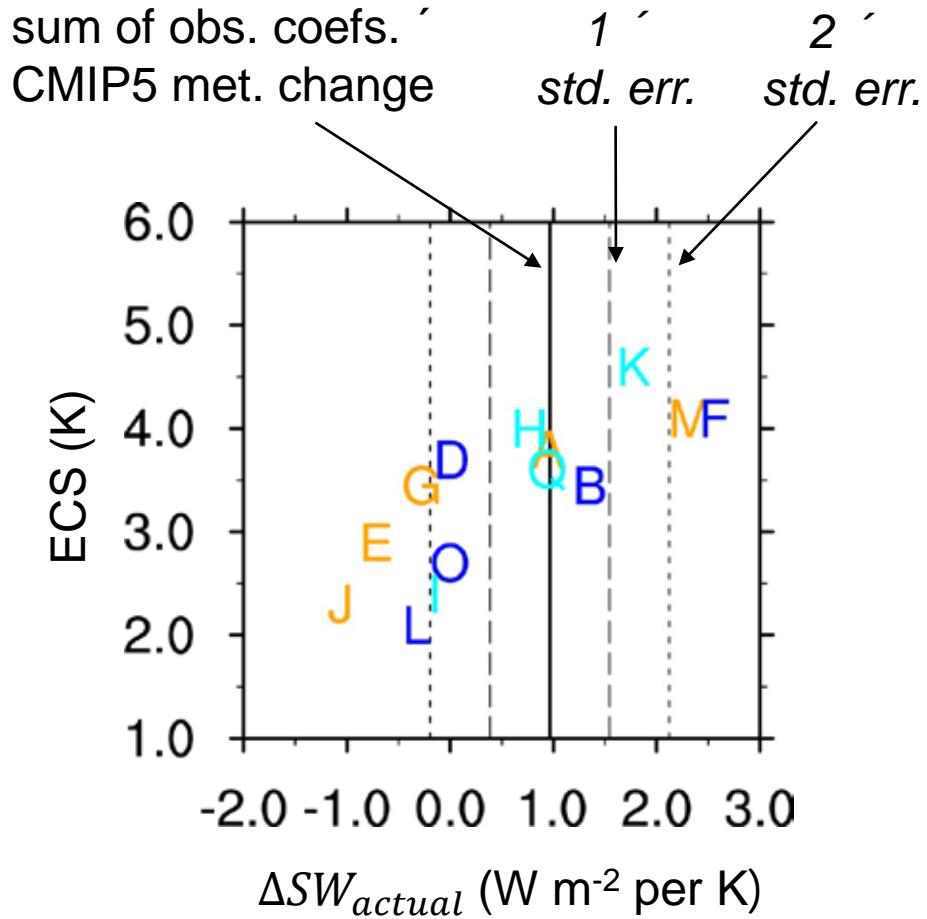
Total SW Cloud Feedback with Observed Coefficients



SW Cloud Feedback and Equilibrium Climate Sensitivity

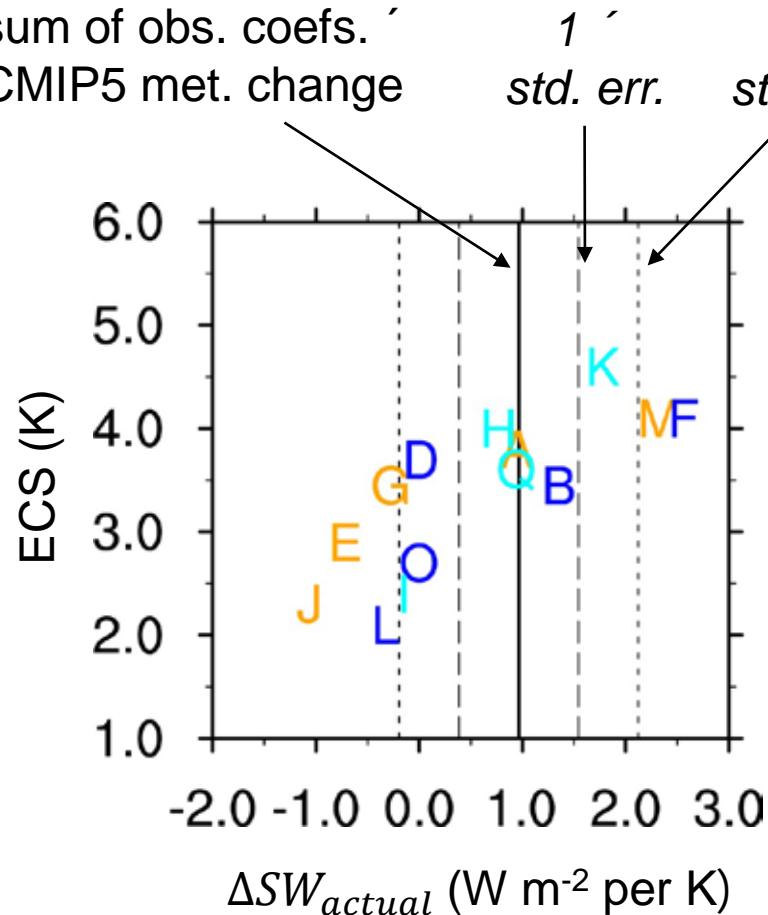


SW Cloud Feedback and Equilibrium Climate Sensitivity



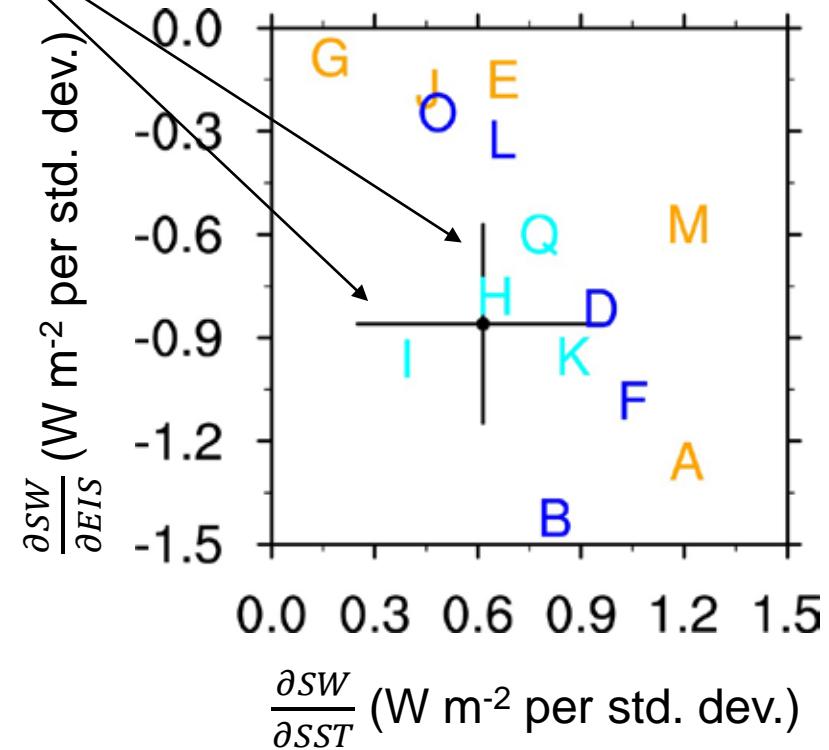
SW Cloud Feedback and Equilibrium Climate Sensitivity

sum of obs. coeffs.
CMIP5 met. change



1 std. err. 2 std. err.

observed
2nd best
best
3rd best



Conclusions

- *Opinion:* Accurate simulation of a comprehensive set of observed interannual cloud-meteorology relationships is a necessary requirement for accurate cloud feedbacks
- The one model – one vote democracy of GCMs must end!
- MBL cloud feedback can be represented as a linear response to changes in large-scale meteorological conditions
- MBL cloud feedback is highly correlated ($r = 0.8$) with equilibrium climate sensitivity in CMIP5 models
- The loosest observational constraint on MBL cloud feedback is the large uncertainty of $\partial SW / \partial SST$

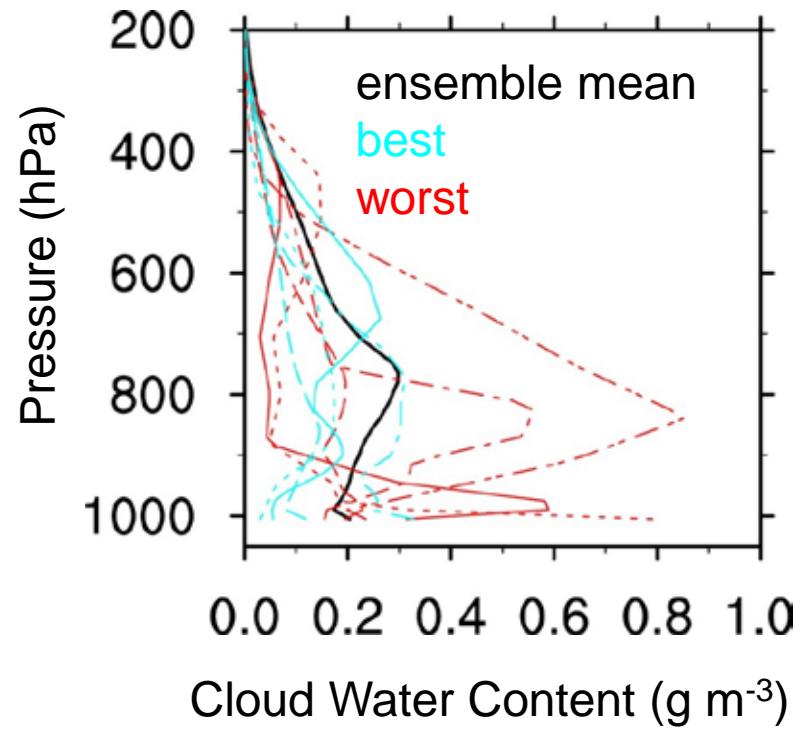
Thank you!

p.s. – A talented recent Ph.D. recipient is now looking for a postdoctoral position

CMIP5 Global Climate Models

ACCESS1.0	A	HadGEM2-ES	K
ACCESS1.3	B	INM-CM4	L
BCC-CSM1.1	C	IPSL-CM5A-LR	M
CanESM2	D	IPSL-CM5B-LR	N
CCSM4	E	MIROC5	O
CSIRO-Mk3.6.0	F	MIROC-ESM	P
FGOALS-g2	G	MPI-ESM-LR	Q
GFDL-CM3	H	MRI-CGCM3	R
GFDL-ESM2G	I	NorESM1-M	S
GISS-E2-H	J		

CMIP5 Cloud Water Content



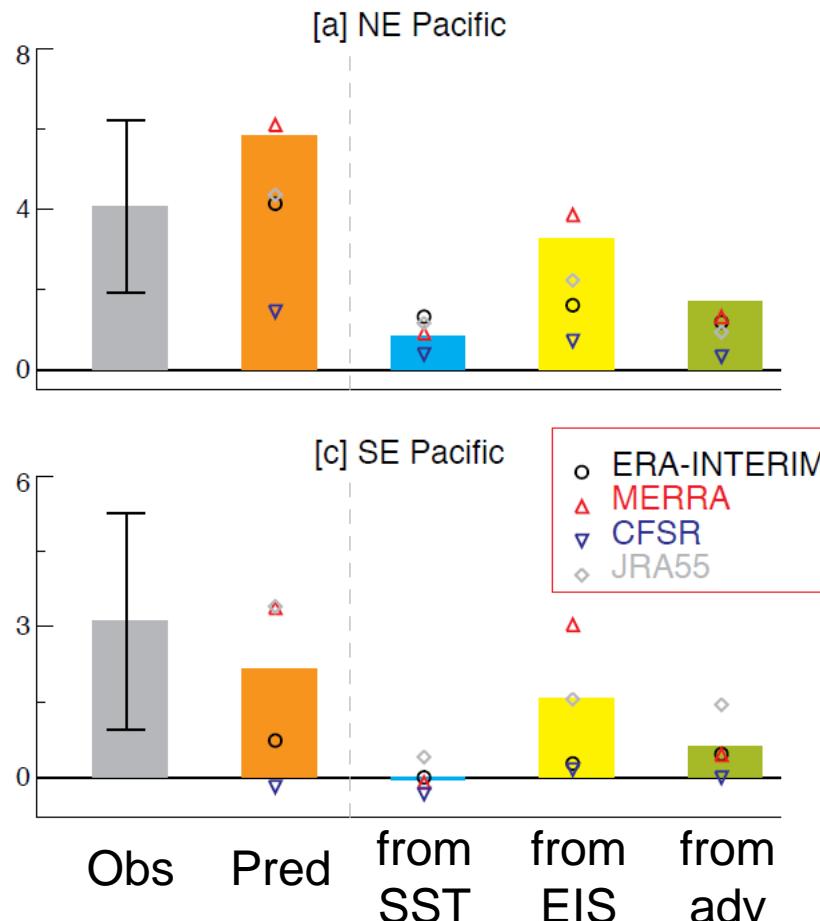
Prediction of 1984-2009 Cloud Trends

$$\Delta CF = \frac{\partial CF}{\partial SST} \Delta SST + \frac{\partial CF}{\partial EIS} \Delta EIS + \frac{\partial CF}{\partial SSTadv} \Delta SSTadv$$

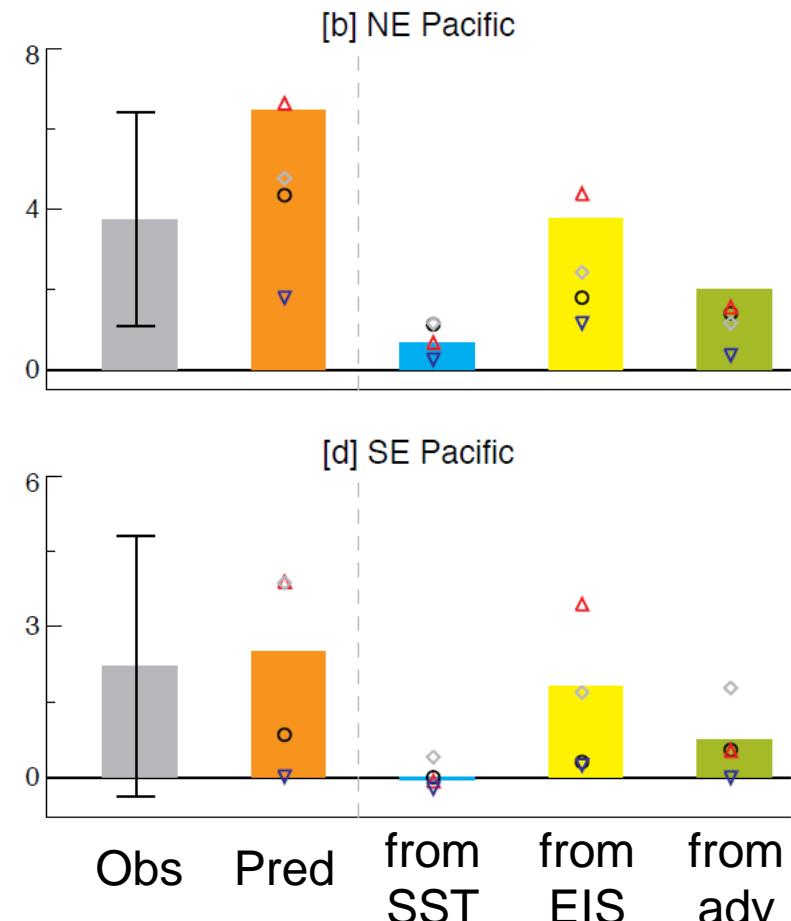
- CF = low+mid-level cloud fraction from ISCCP/PATMOS-x
- artifacts have been removed from satellite cloud records
- meteorological trends from reanalyses
- negligible contribution from RH₇₀₀ and w₇₀₀

Prediction of 1984-2009 Cloud Trends

ISCCP

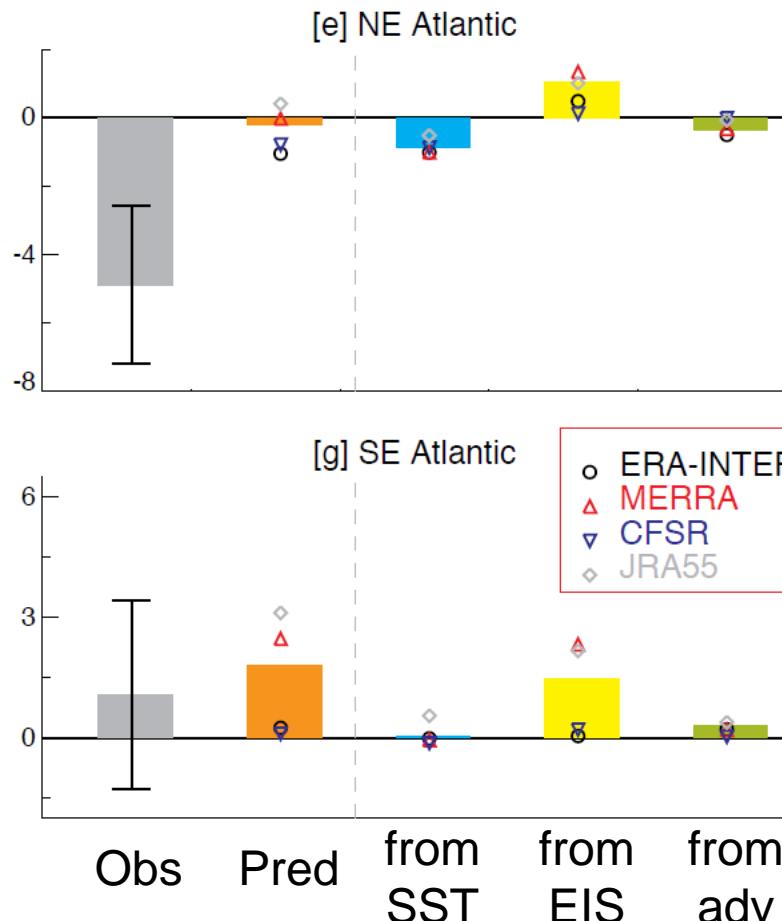


PATMOS-x

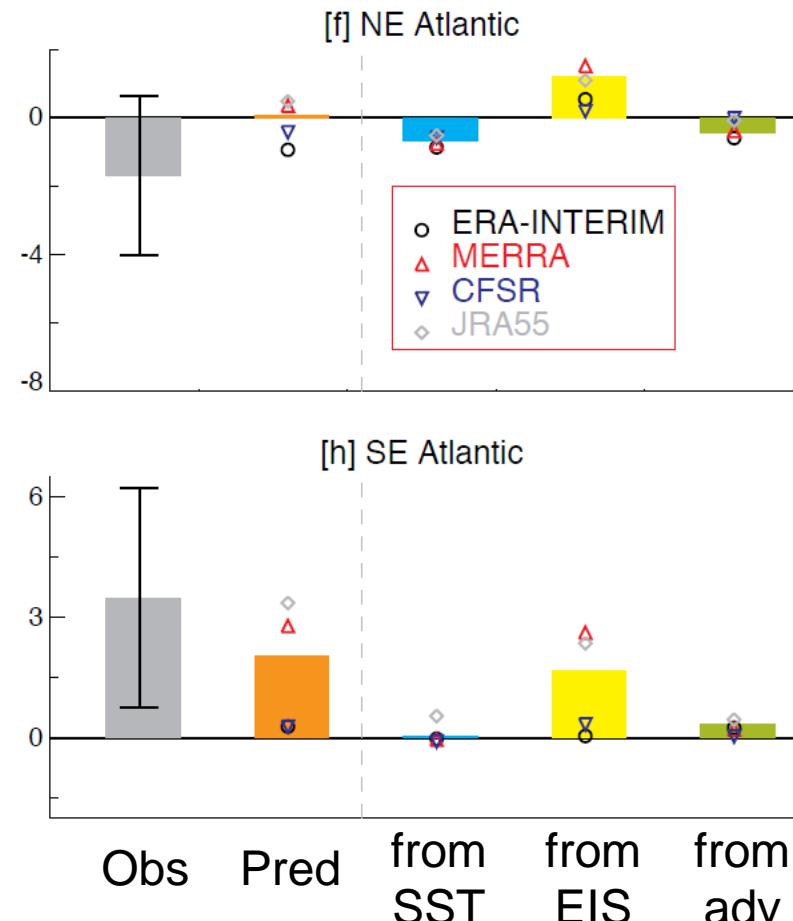


Prediction of 1984-2009 Cloud Trends

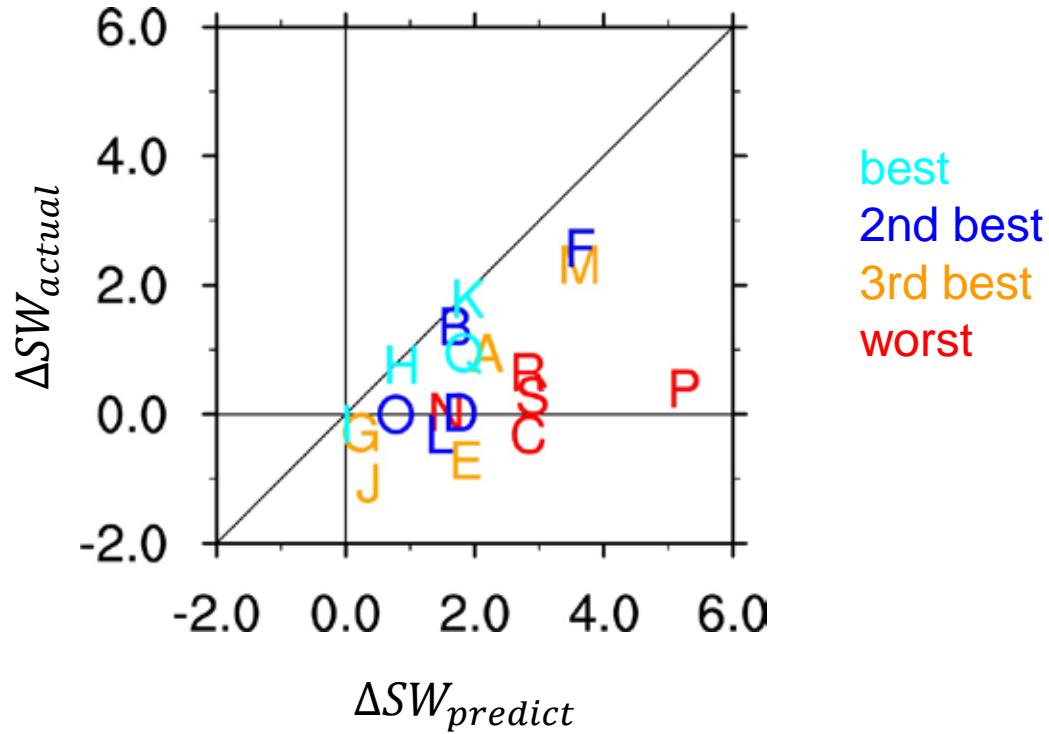
ISCCP



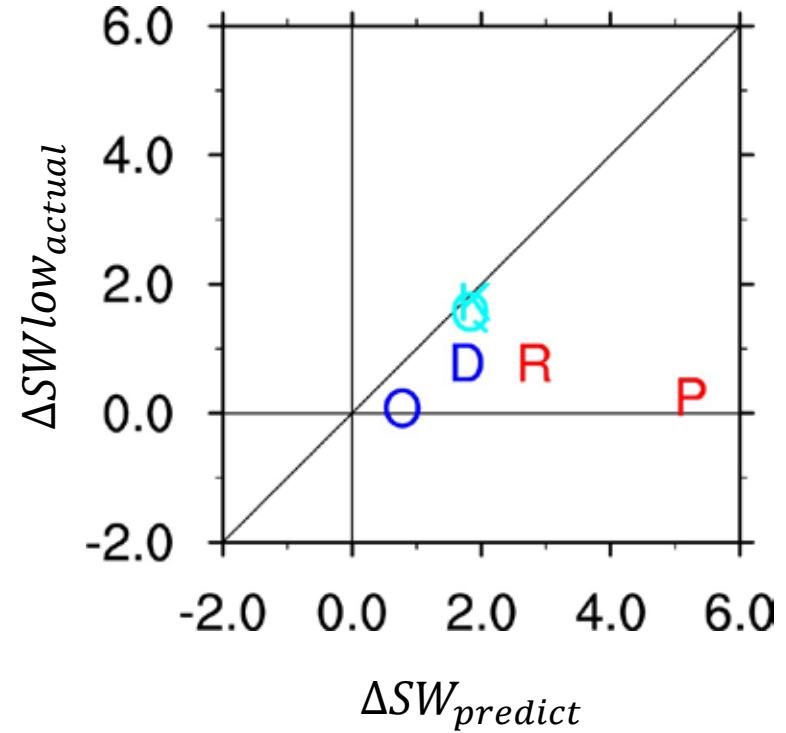
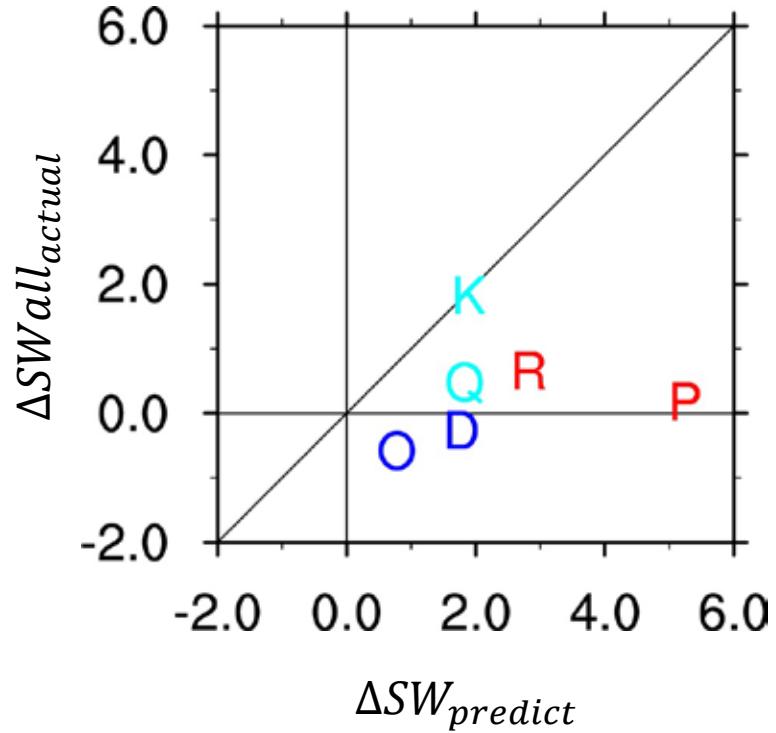
PATMOS-x



Predicted and Actual CMIP5 SW Cloud Feedback



Predicted and Actual for All Clouds and Low-level Clouds



obtained from ISCCP simulator output