The simulation of interannual variability of subtropical clouds in CMIP3 and CMIP5 models compared to retrievals from CERES, ISCCP, and CALIPSO

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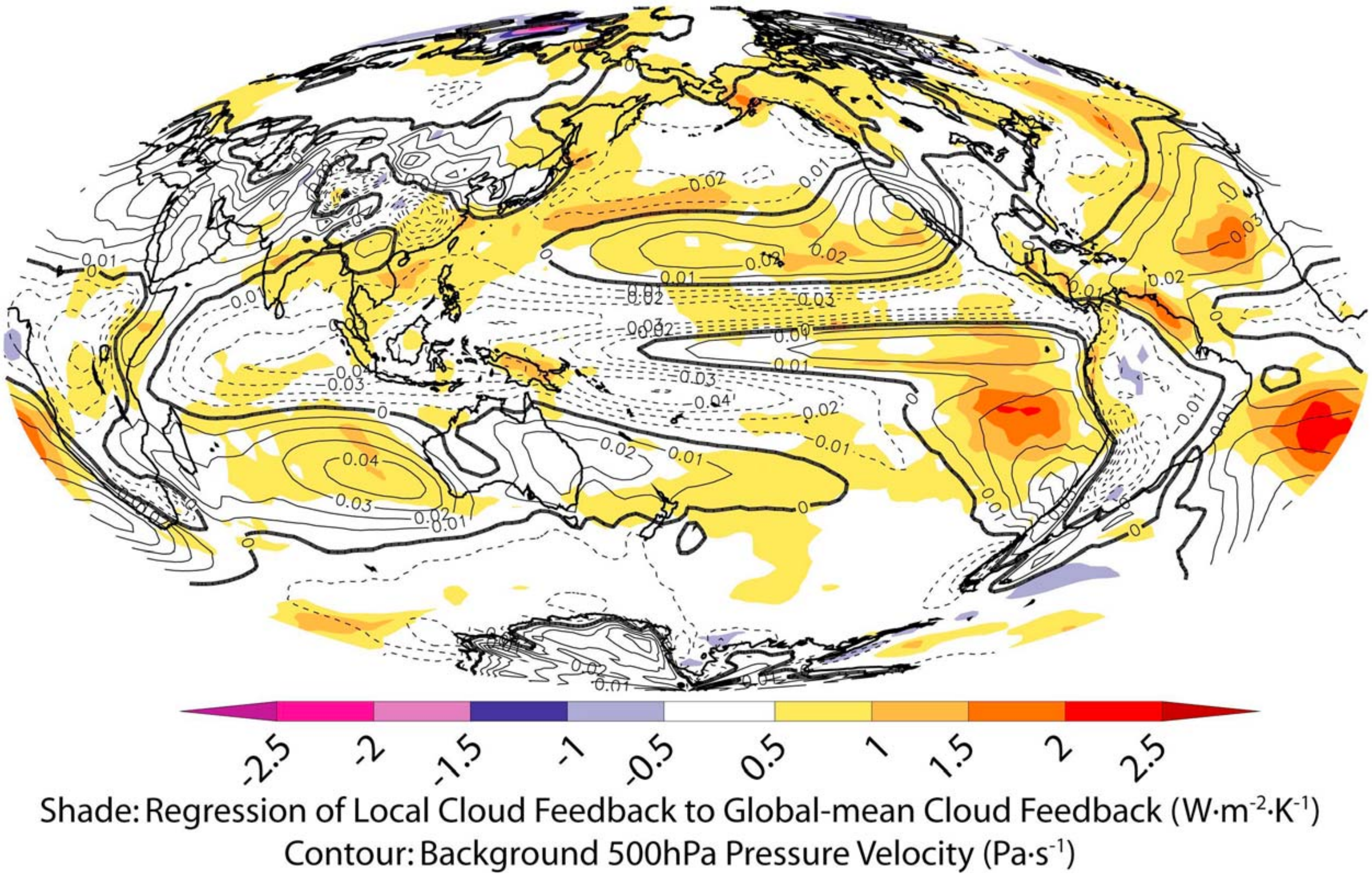
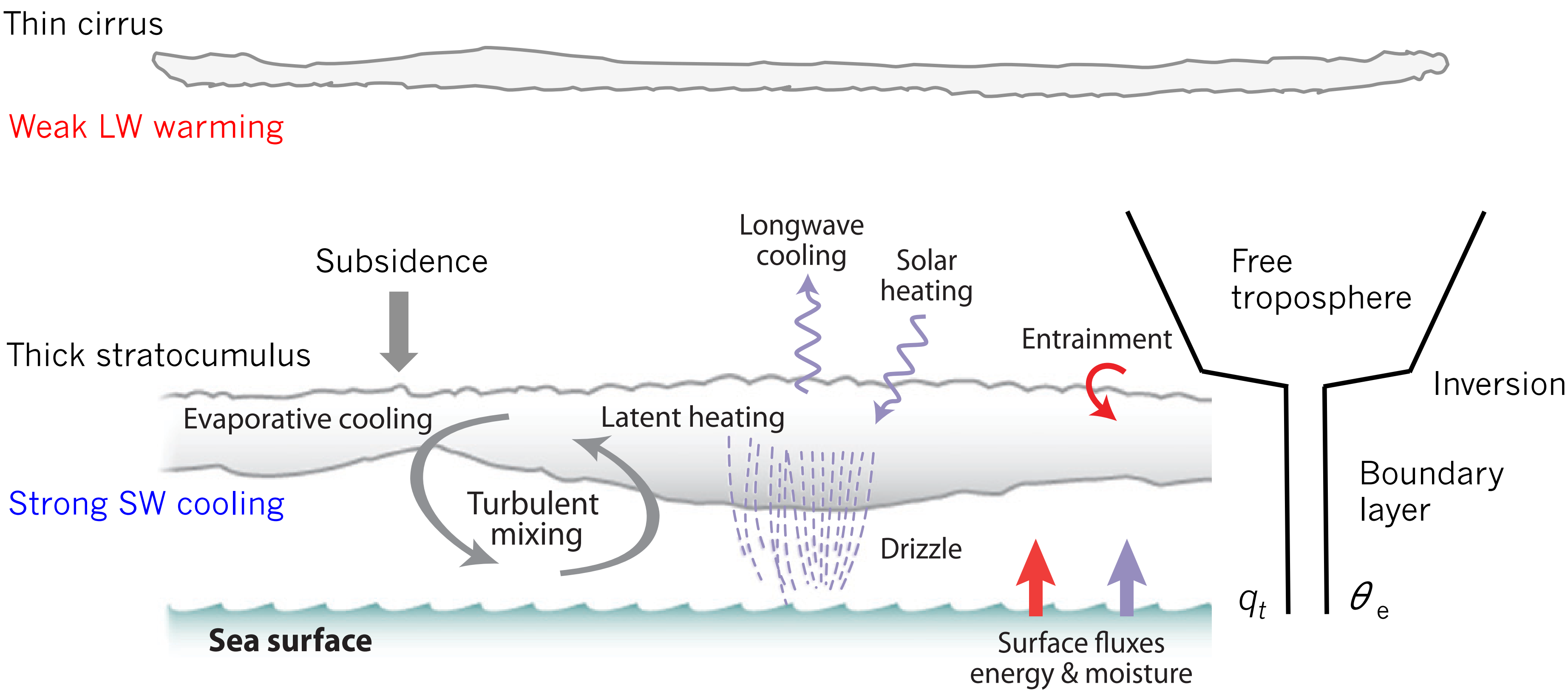
Low-level clouds over subtropics drive uncertainty in cloud feedbacks



Soden and Vecchi 2011

Physics of stratocumulus-topped boundary layer



Wood 2012

θ_e = equivalent potential temperature
q_t = total water mixing ratio

Observed correlations between MBL clouds and large-scale meteorology

- Stronger inversion → more cloud
- Cooler sea surface temperature → more cloud
- Faster surface wind speed/cold air advection → more cloud
- Weaker subsidence → more cloud
- Free-tropospheric moisture → ?

Data

Observational Dataset	Time Period Used	Variables Used	n_{eff}/n
ISCCP	1984-2009	CF SW CRE LW CRE	1/72* 1/60 1/96
CALIPSO-GOCCP	2001-2009	CF	1/10
CERES	2001-2009	SW CRE LE CRE	1/36 1/36
HadISST	coincident w/paired cloud data	SST	
CFSR	same	EIS = EIS(SST, SLP, T_{700}, z_{700}) , V, ω_{700}, q_{700}	
ERA-Interim	same	same	
JRA-25	same but through 2007	same	
MERRA	same	same	

Cloud radiative effect (CRE in W m^{-2}): clear sky minus all sky top of atmosphere outgoing radiation (positive outward) – shortwave, longwave, or net

SW CRE < 0

LW CRE > 0

Data

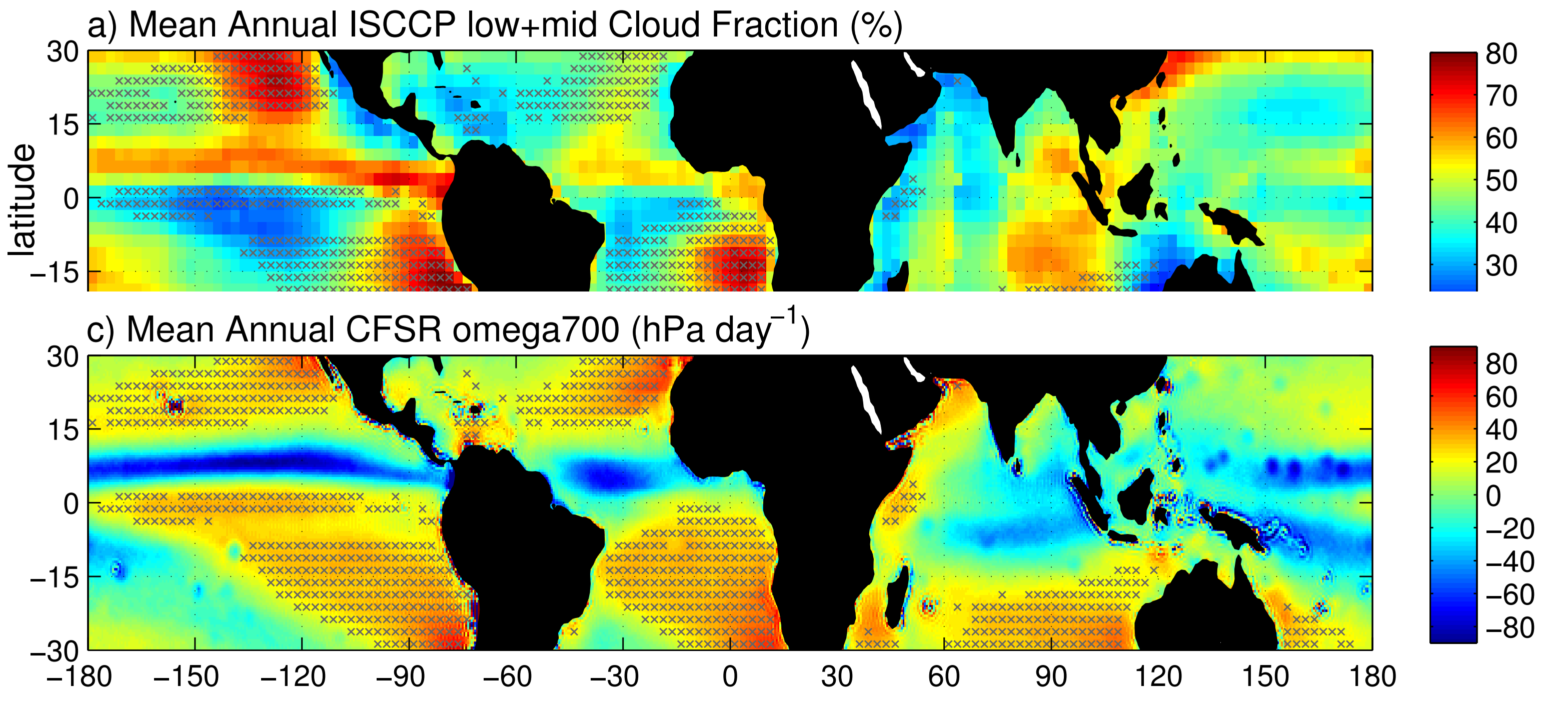
Modeling Group	CMIP3 Models	ID	CMIP5 Models	ID
National Center for Atmospheric Research	CCSM3 PCM	1a 1b	CCSM4 CESM1 (CAM5)	1a 1b
Canadian Centre for Climate Modelling and Analysis	CGCM3.1 (T47)	2	CanESM2	2
Max Planck Institute for Meteorology	ECHAM5	3	MPI-ESM-LR	3
LASG / Institute of Atmospheric Physics	FGOALS-g1.0	4	FGOALS-g2	4
NOAA Geophysical Fluid Dynamics Laboratory	GFDL-CM2.0	5	GFDL-CM3 GFDL-ESM2G	5a 5b
NASA Goddard Institute for Space Studies	GISS-EH	6	GISS-E2-H	6
Institut-Pierre Simon Laplace	IPSL-CM4	7	ISPL-CM5A-LR IPSL-CM5B-LR	7a 7b
Japan Agency for Marine-Earth Science and Technology, Atmosphere and Ocean Research Institute (The University of Tokyo), and National Institute for Environmental Studies	MIROC3.2 (hires)	8	MIROC5 MIROC-ESM-CHEM	8a 8b
Meteorological Research Institute	MRI-CGCM2.3.2	9	MRI-CGCM3	9
Met Office Hadley Centre	UKMO-HadCM3	10	HadGEM2-ES	10

We use:

- Models from modeling centers participating in both CMIP3 and CMIP5
- CMIP3 and CMIP5 historical runs concurrent with ISCCP record (26 years)
- ISCCP/CALIPSO CF for the six CMIP5 models providing such data

Methods

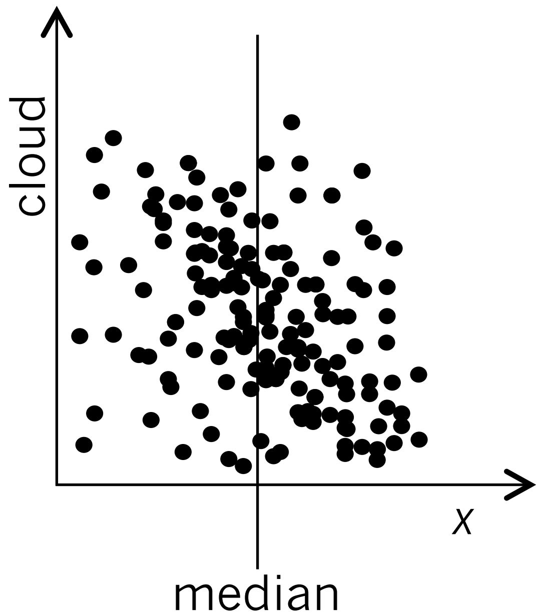
- Domain is dynamically rather than spatially defined, as in Bony et al. (2004). Includes all oceanic grid boxes within 30°S-30°N that experience subsidence.
- Seasonal cycle of each grid box is removed and anomalies are then detrended.



Methods

The sensitivity of a cloud property CF or CRE with respect to a meteorological parameter *x* is defined as

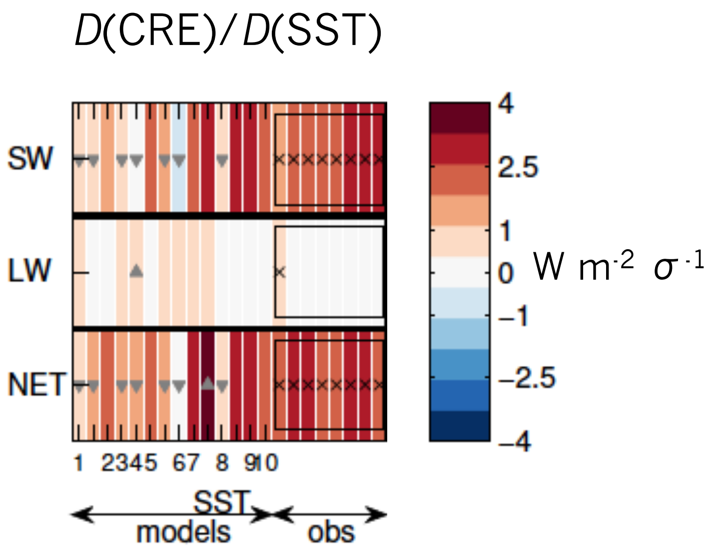
$$\frac{D(\text{cloud})}{D(x)} = \frac{\overline{\text{cloud}(x>m)} - \overline{\text{cloud}(x<m)}}{\overline{x(x>m)} - \overline{x(x<m)}}$$



Examining the sensitivity of the vertical profile of CF will allow us to elucidate the modeled and observed sensitivity of SW, LW, and NET CRE.

Results
Sensitivity of SW, LW, and NET CRE

CMIP5



X *D*(CRE)/*D*(*x*) obs significant

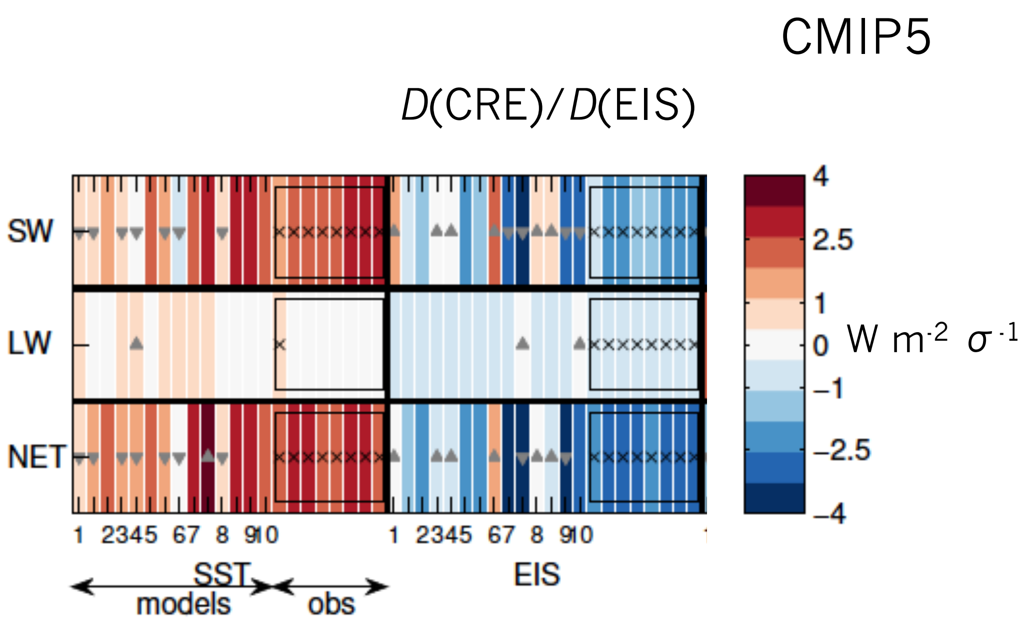
▼ *D*(CRE)/*D*(*x*) model < *D*(CRE)/*D*(*x*) obs

▲ *D*(CRE)/*D*(*x*) model > *D*(CRE)/*D*(*x*) obs

Observations:
cool SST
→ strongly enhances SW CRE (cooling effect)
→ no change in LW CRE
→ more negative NET CRE

 # models outside of range of observational uncertainty:
50%
7%
57%

Results
Sensitivity of SW, LW, and NET CRE



X *D*(CRE)/*D*(*x*) obs significant

▼ *D*(CRE)/*D*(*x*) model < *D*(CRE)/*D*(*x*) obs

▲ *D*(CRE)/*D*(*x*) model > *D*(CRE)/*D*(*x*) obs

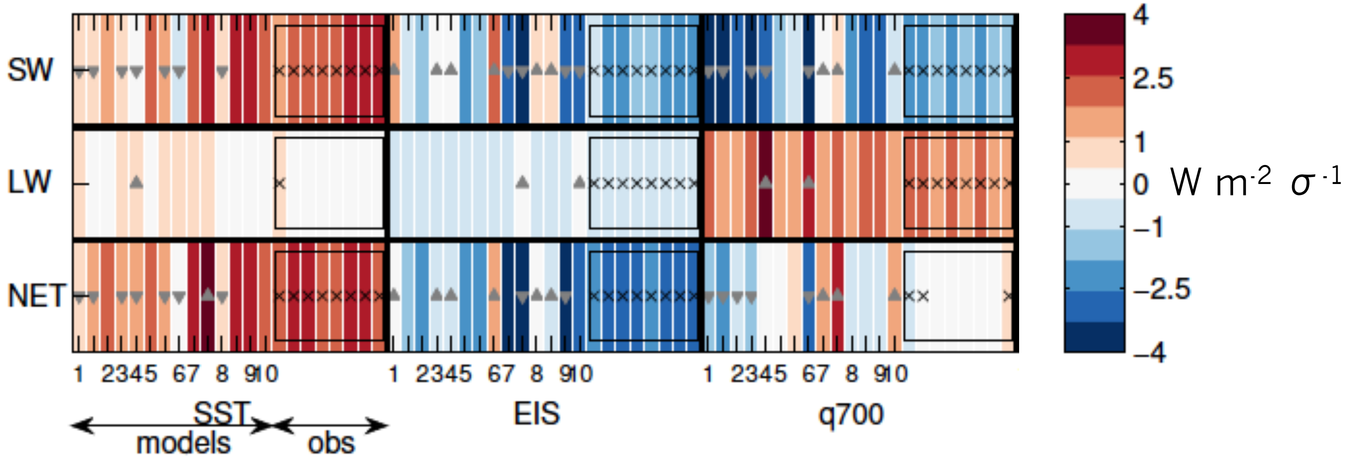
Observations:
strong EIS
→ strongly enhances SW CRE (cooling effect)
→ slightly weakens LW CRE (cooling effect)
→ more negative NET CRE

 # models outside of range of observational uncertainty:
71%
14%
57%

Results
Sensitivity of SW, LW, and NET CRE

CMIP5

$D(\text{CRE})/D(q_{700})$



X $D(\text{CRE})/D(x)$ obs significant

▼ $D(\text{CRE})/D(x)$ model < $D(\text{CRE})/D(x)$ obs

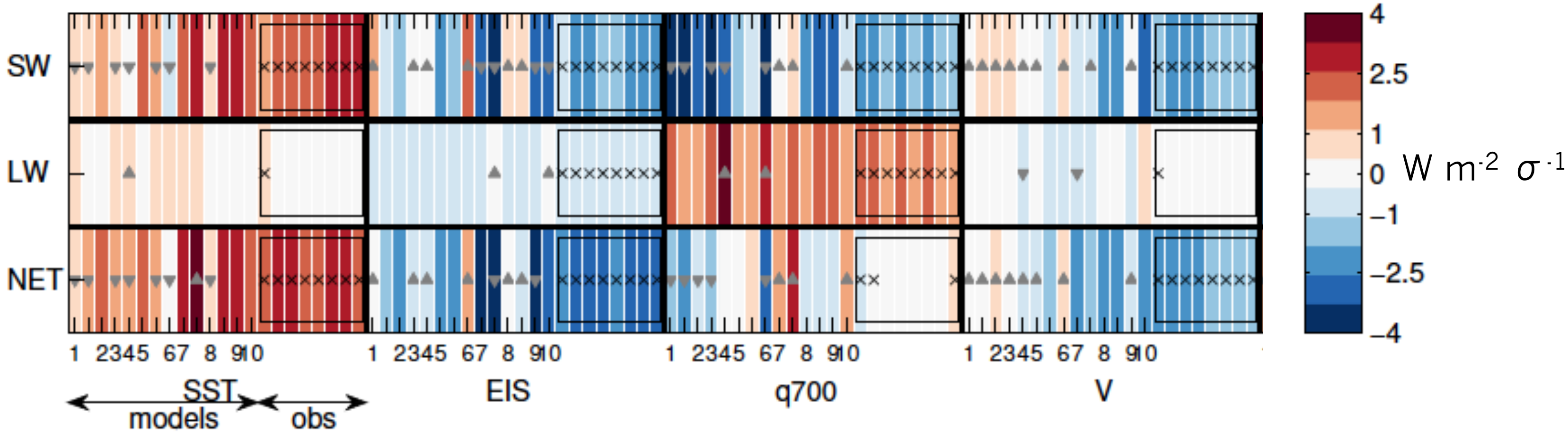
▲ $D(\text{CRE})/D(x)$ model > $D(\text{CRE})/D(x)$ obs

Observations:	**# models outside of range of observational uncertainty:**
moist q_{700}	
→ strongly enhances SW CRE (cooling effect)	57%
→ strongly enhances LW CRE (warming effect)	14%
→ no change in NET CRE	57%

Results
Sensitivity of SW, LW, and NET CRE

CMIP5

D(CRE)/*D*(*V*)



X *D*(CRE)/*D*(*x*) obs significant

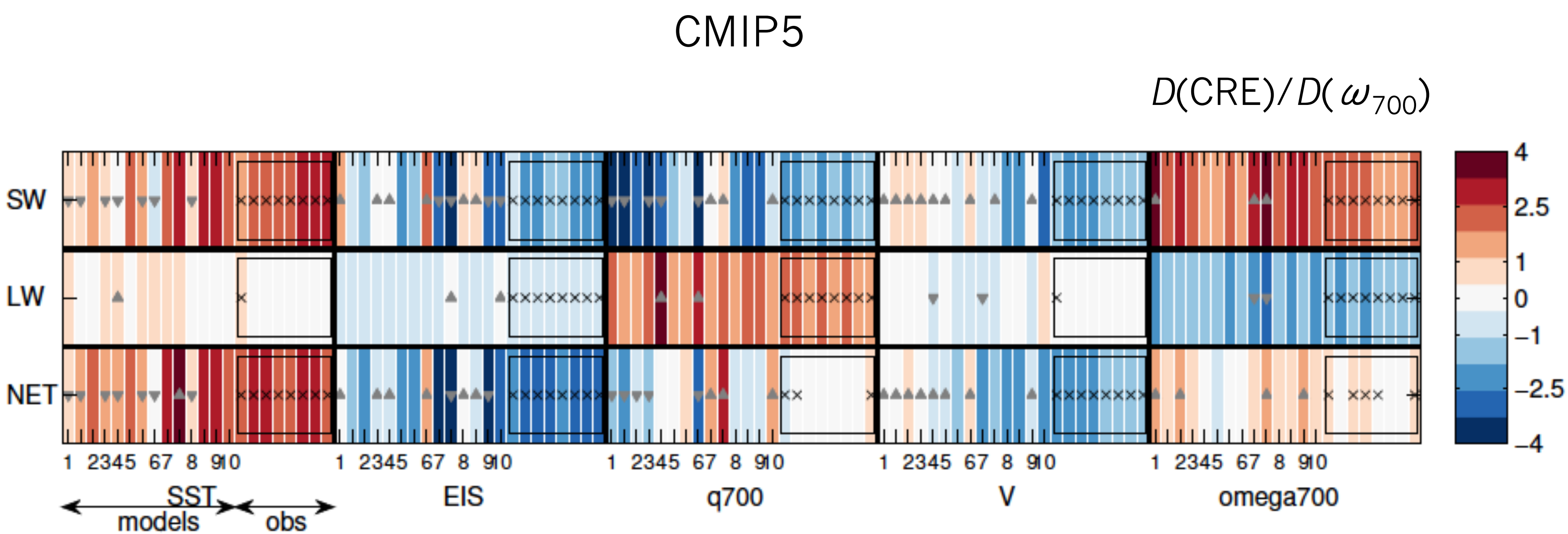
▼ *D*(CRE)/*D*(*x*) model < *D*(CRE)/*D*(*x*) obs

▲ *D*(CRE)/*D*(*x*) model > *D*(CRE)/*D*(*x*) obs

Observations:
fast *V*
→ strongly enhances SW CRE (cooling effect)
→ no change in LW CRE
→ more negative NET CRE

 # models outside of range of observational uncertainty:
64%
14%
57%

Results
Sensitivity of SW, LW, and NET CRE



X *D*(CRE)/*D*(*x*) obs significant

▼ *D*(CRE)/*D*(*x*) model < *D*(CRE)/*D*(*x*) obs

▲ *D*(CRE)/*D*(*x*) model > *D*(CRE)/*D*(*x*) obs

Observations:	**# models outside of range of observational uncertainty:**
weak ω_{700}	
→ strongly enhances SW CRE (cooling effect)	21%
→ strongly enhances LW CRE (warming effect)	14%
→ no change in NET CRE	29%

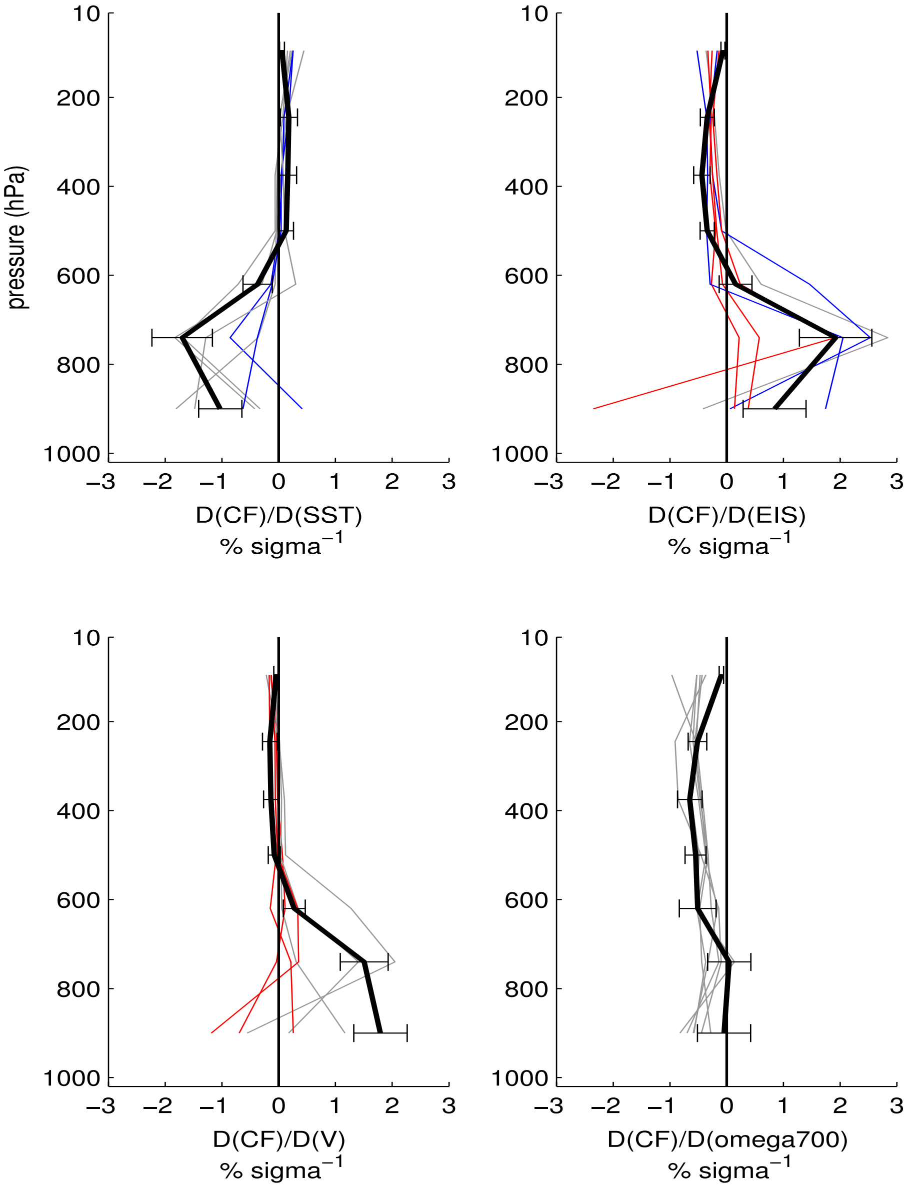
Results

Sensitivity of SW, LW, and NET CRE

		SST	**EIS**	q_{700}	V	ω_{700}
SW	**CMIP3**	36%	36%	45%	73%	45%
	CMIP5	50%	71%	57%	64%	21%
LW	**CMIP3**	18%	64%	18%	09%	18%
	CMIP5	7%	14%	14%	14%	14%
NET	**CMIP3**	36%	27%	45%	73%	27%
	CMIP5	57%	57%	57%	57%	29%

Percentage of models simulating SW, LW, and NET CRE sensitivity estimates outside the range of observational uncertainty.

Results
Sensitivity of CF and effect on SW CRE



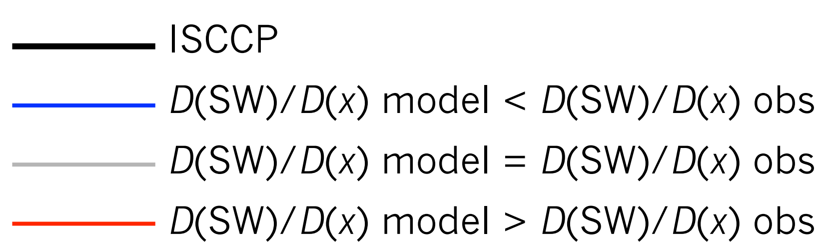
Observations:

cool SST, strong EIS, fast *V*
→ increases low-level CF
→ enhances SW CRE

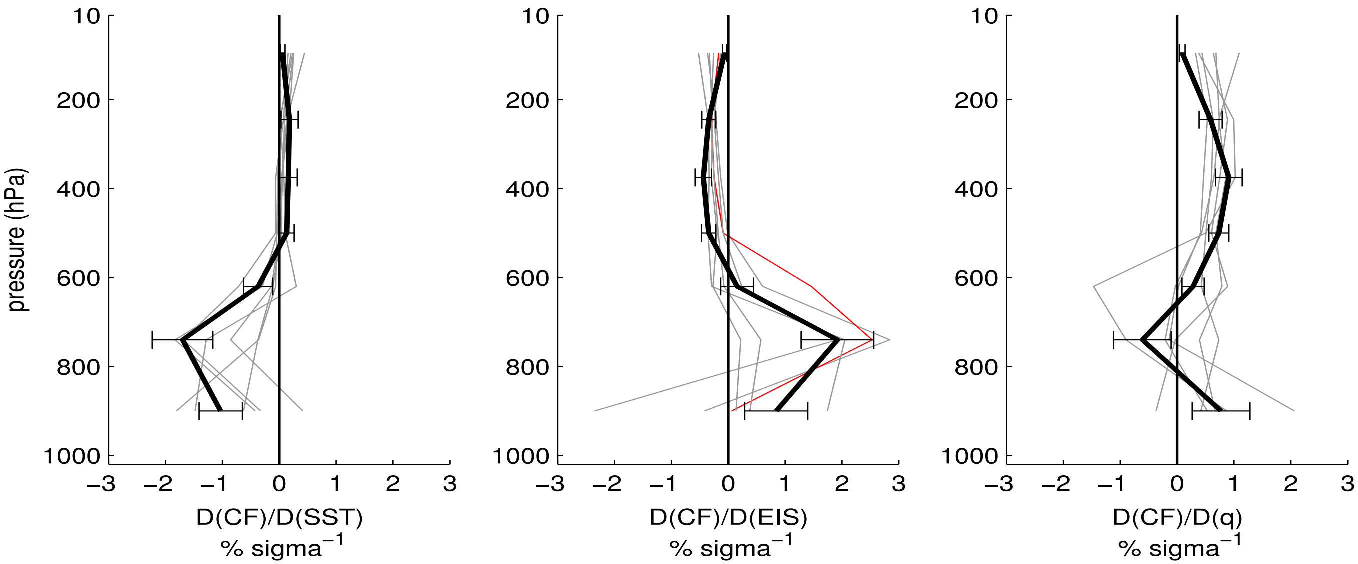
moist q_{700}, weak ω_{700}
→ increases low-level and high-level CF
→ enhances SW CRE

CMIP5 models:

simulation of low-level CF sensitivity consistent with SW CRE sensitivity



Results
Sensitivity of CF and effect on LW CRE

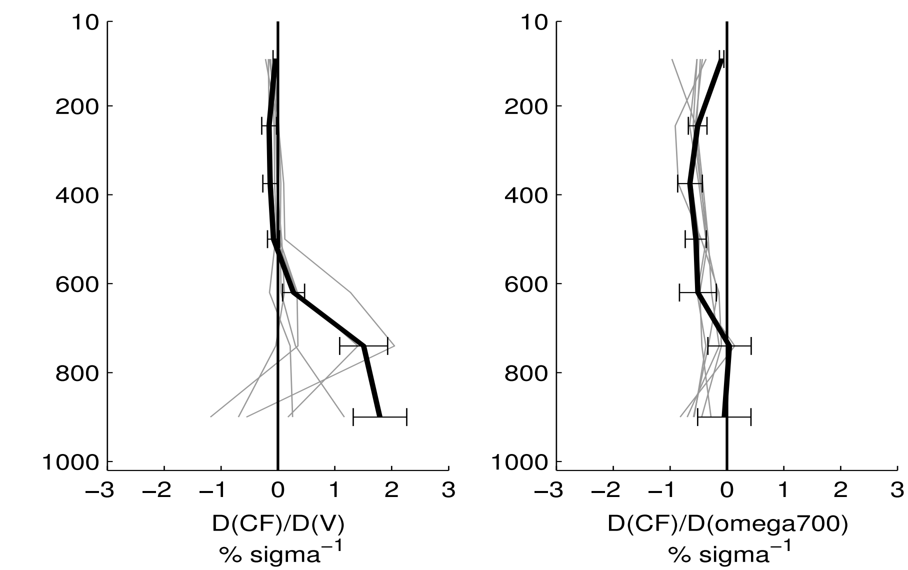


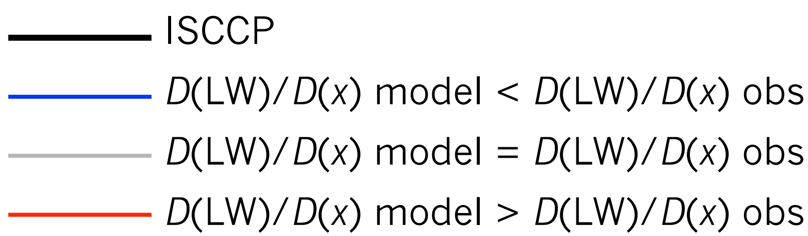
Observations:

moist q_{700}, weak ω_{700}
→ increases high-level CF
→ enhances LW CRE

CMIP5 models:

good





Summary and Conclusion

- Subtropical low-level clouds
  - (1) Large-scale meteorology → (2) turbulent processes → (3) marine boundary layer clouds
  - Poorly simulated by models because (2) not resolved
  - CMIP5 worse than CMIP3
- Subtropical high-level clouds
  - (1) Large-scale meteorology → (2) cirrus
  - Well simulated by models because (1) resolved

Thanks for listening!

Extra slides

Results
Sensitivity of SW, LW, and NET CRE

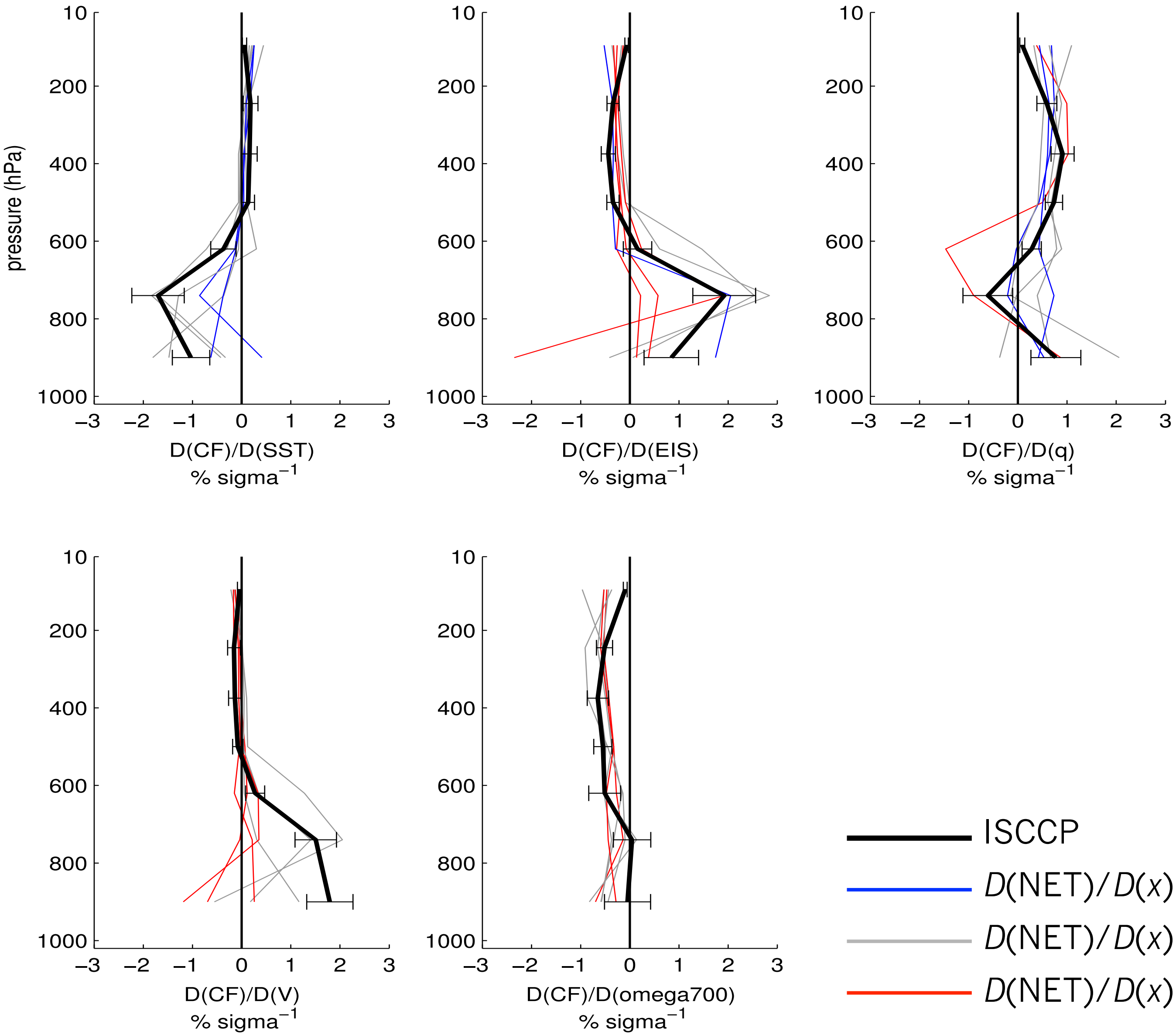
		SST	EIS	q_{700}	V	ω_{700}
SW	**CMIP3**	0.61**	0.81**	1.5	1.3	1
	CMIP5	1.2**	2.2**	1.7	1.2	0.82
LW	**CMIP3**	0.34	0.54*	0.64	0.4	0.38
	CMIP5	0.28	0.34*	0.55	0.42	0.38
NET	**CMIP3**	0.46**	0.65**	1.1	1	0.79
	CMIP5	1.1**	1.9**	1.5	1	0.65

** (*) indicates that the CMIP5 standard deviation of a sensitivity estimate is greater (less) than the CMIP3 standard deviation with statistical significance at the 95% (90%) confidence level

Intermodel standard deviation of normalized SW, LW, and NET CRE sensitivity estimates ($W\ m^{-2}\ \sigma^{-1}$).

Results

Sensitivity of CF and effect on NET CRE

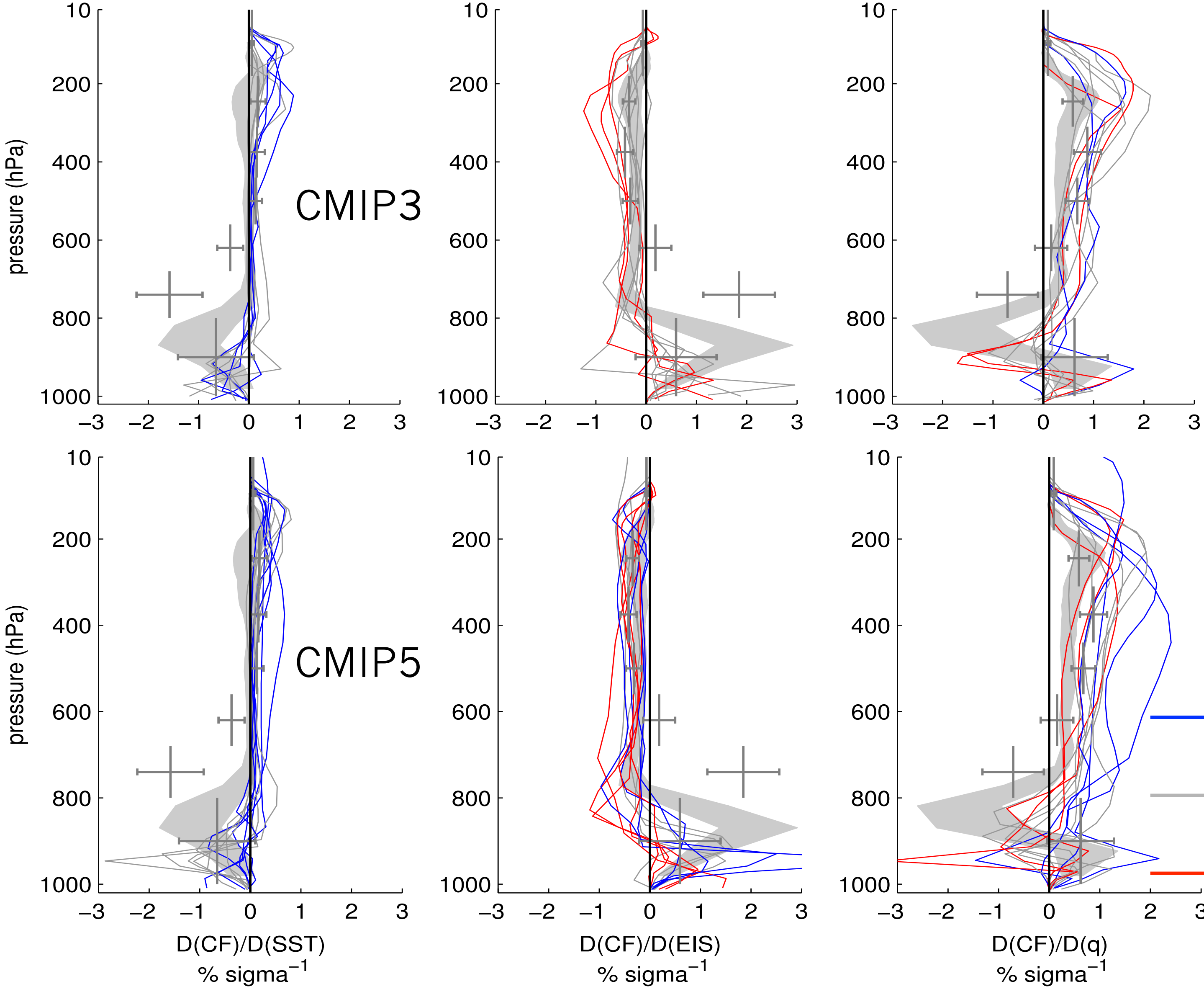


Observations:
cool SST, strong EIS, fast *V*
→ large low-level CF
→ more negative NET CRE

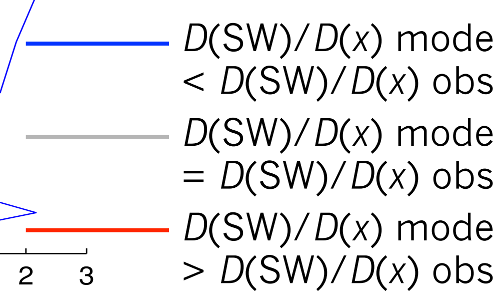
moist q_{700}, weak ω_{700}
→ large low-level and high-level CF
→ no change in NET CRE

CMIP5 models:
simulation of low-level CF sensitivity consistent with NET CRE sensitivity

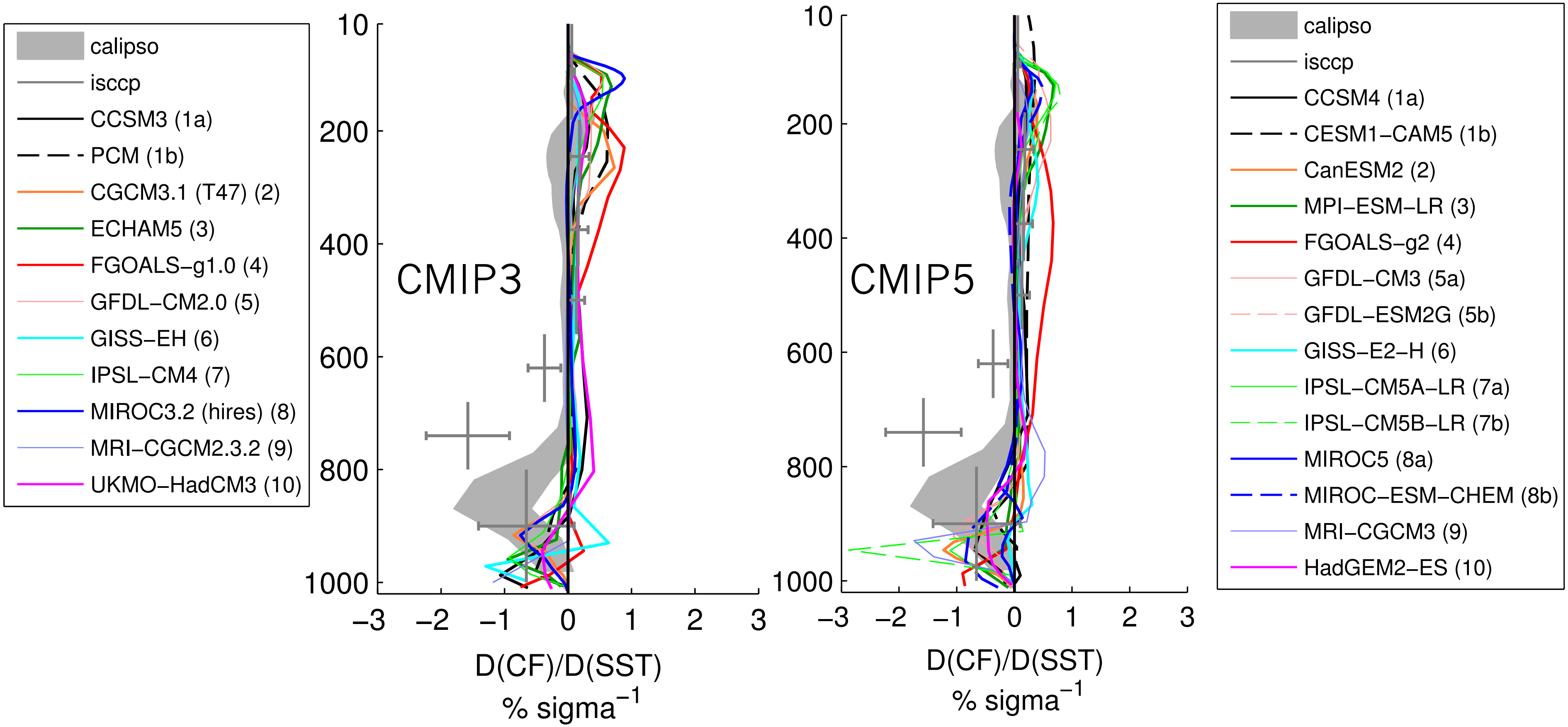
Results
CMIP3 vs. CMIP5



More CMIP5 models than CMIP3 models tend to underestimate or (overestimate) the enhanced SW CRE due to cooler SST, stronger EIS, or moister q_{700} due to underestimating or (overestimating) the increase in low-level CF due to these effects.

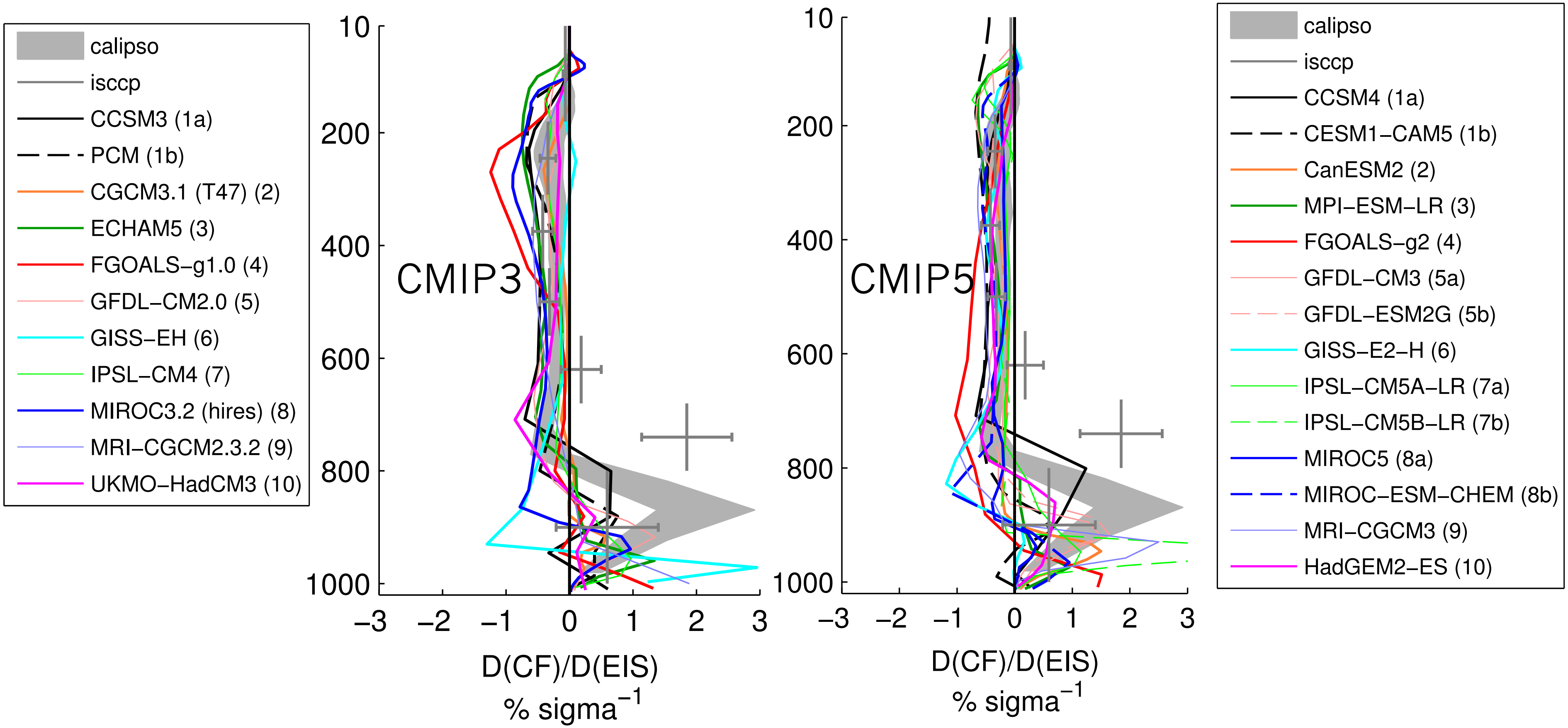


Results
CMIP3 vs. CMIP5



CMIP3 models that simulate D(SW)/D(SST) within range of obs uncertainty:
CCSM3, GISS-EH, MIROC3.2 (hires)
CMIP5 models that simulate D(SW)/D(SST) outside range of obs uncertainty:
CCSM4, CESM1-CAM5, GISS-E2-H, MIROC5

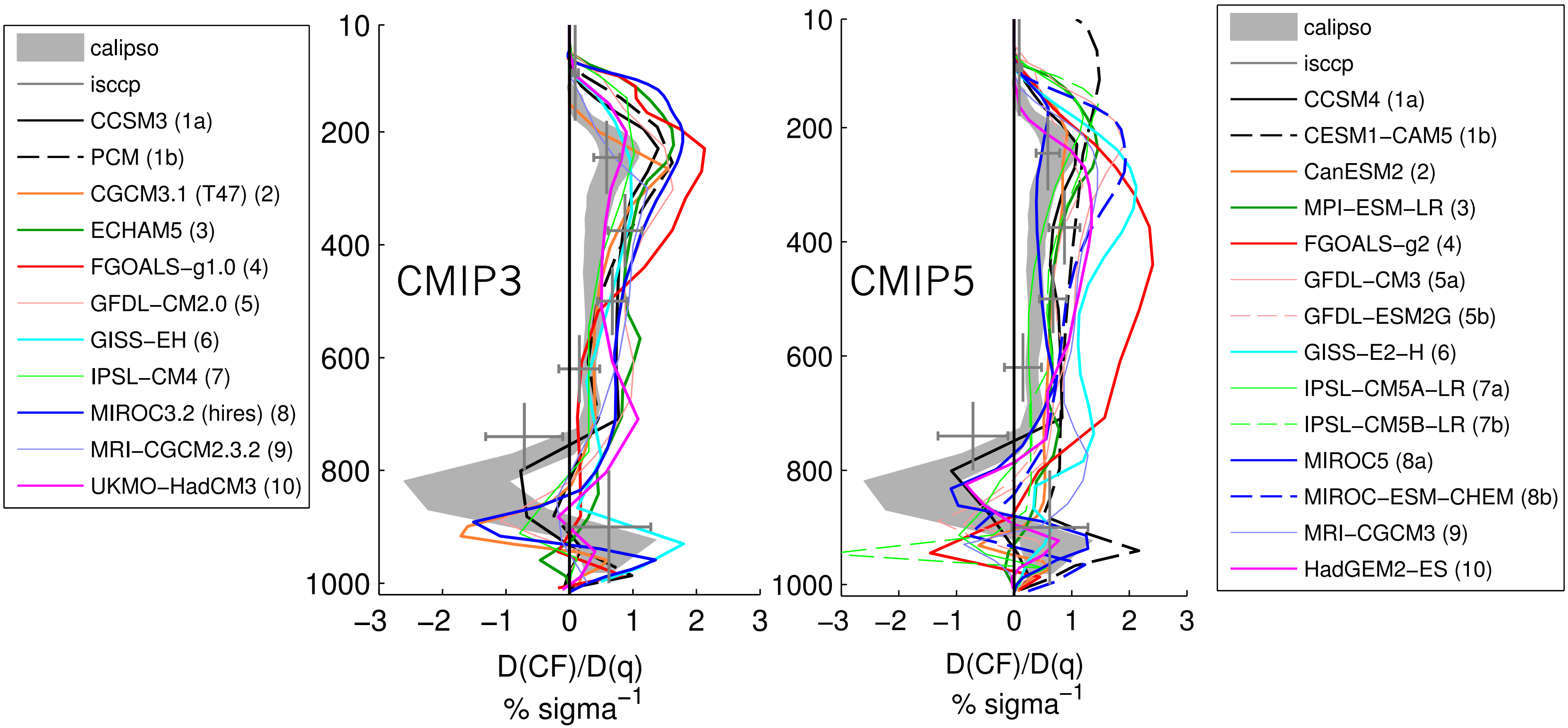
Results
CMIP3 vs. CMIP5



CMIP3 models that simulate D(SW)/D(EIS) within range of obs uncertainty:
GISS-EH, IPSL-CM4, MRI-CGCM2.3.2, **UKMO-HadCM3**

CMIP5 models that simulate D(SW)/D(EIS) outside range of obs uncertainty:
GISS-E2-H, IPSL-CM5A-LR, IPSL-CM5B-LR, MRI-CGCM3, **HadGEM2-ES**

Results
CMIP3 vs. CMIP5



CMIP3 models that simulate D(SW)/D(q_{700}) within range of obs uncertainty:
FGOALS-g1.0, IPSL-CM4, UKMO-HadCM3

CMIP5 models that simulate D(SW)/D(q_{700}) outside range of obs uncertainty:
FGOALS-g2, IPSL-CM5A-LR, IPSL-CM5B-LR, HadGEM2-ES

Results
CMIP5 mean cloud water content

The mean state also matters!