

Evaluating Cloud Radiative Effects in CMIP5 Models using CERES EBAF Data

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Data

- CERES EBAF (Ed2.6)
 - TOA; 2000/3 – 2010/12
- CMIP5 AMIP
 - AGCM forced with observed monthly SST and ice fraction
 - 12 models
 - 6 models provide satellite simulator output
 - 1979 – 2008
- 2001-2008

CMIP5 Models

Model	Country	Nx*ny	Lon*lat
CanAM4*	Canada	128x64	2.8x2.8
CNRM-CM5*	France	256x128	1.4x1.4
GFDL-HIRAM-C360	US-GFDL	1152x720	0.3125x0.25
GISS-E2-R	US-NASA GISS	144x90	2.5x2
HadGEM2-A*	UK	192x145	1.875x1.25
inmcm4	Russia	180x120	2x1.5
IPSL-CM5A-LR*	France	96x96	3.75x1.9
MIROC5*	Japan	256x128	1.4x1.4
MPI-ESM-LR*	Germany	192x96	1.875x1.865
MRI-AGCM3-2S	Japan	1920x960	0.18x0.18
MRI-CGCM3	Japan	320x160	1.125x1.121
NorESM1-M	Norway	144x96	2.5x1.9

* Models that provide satellite simulator output

High resolution (2): GFDL(1); MRI-AGCM3-2S(1)
 1-deg (4): CNRM; HadGEM2; MIROC5; MRI-CGCM3
 2-deg (6): CanAM4; GISS; inmcm4; IPSL; MPI; NorESM1-M

North America (3)
 Asia (4)
 Europe (5)

Data (Cont'd)

- Other
 - GCM-Oriented CALIPSO Cloud Product (CALIPSO-GOCCP)
 - Designed to evaluate cloudiness in GCMs (Chepfer *et al.* 2010):
 - Derived from CALIPSO L1/NASA products
 - Processed at LMD/IPSL, France
 - Diagnose cloud properties from CALIPSO observations in the same way as in the satellite simulator: same spatial resolution, same threshold for cloud detection
 - 3-D, high, mid and low cloud fraction
 - 2006/6-2010/12
 - ERA Interim: ω at 500mb
 - Proxy for tropical atmospheric circulation

TOA Radiative Budget Comparison: Global Mean

Parameters (W/m ²)	12ModelMean	CERES	12ModelMean-CERES	σ (12Models-12ModelMean)
Incoming Solar↓	341.3	340.2	1.1(0.3%)	0.5
Shortwave↑	101.8	99.9	1.9(1.9%)	2.7
Longwave↑	238.9	239.8	-0.9(-0.4%)	2.8
Net↓	0.6	0.5	0.1(20%)	
Clear Shortwave↑	54.1	52.5	1.6(3.0%)	2.3
Clear Longwave↑	263.3	266.3	-3.0(-1.1%)	3.1
Clear Net↓	23.9	21.4	2.5(11.7%)	
Shortwave CRF	-47.7	-47.4	-0.3(0.6%)	4.4
Longwave CRF	24.4	26.5	-2.1(-7.9%)	3.3
Net CRF	-23.3	-20.9	-2.4(11.3%)	3.7

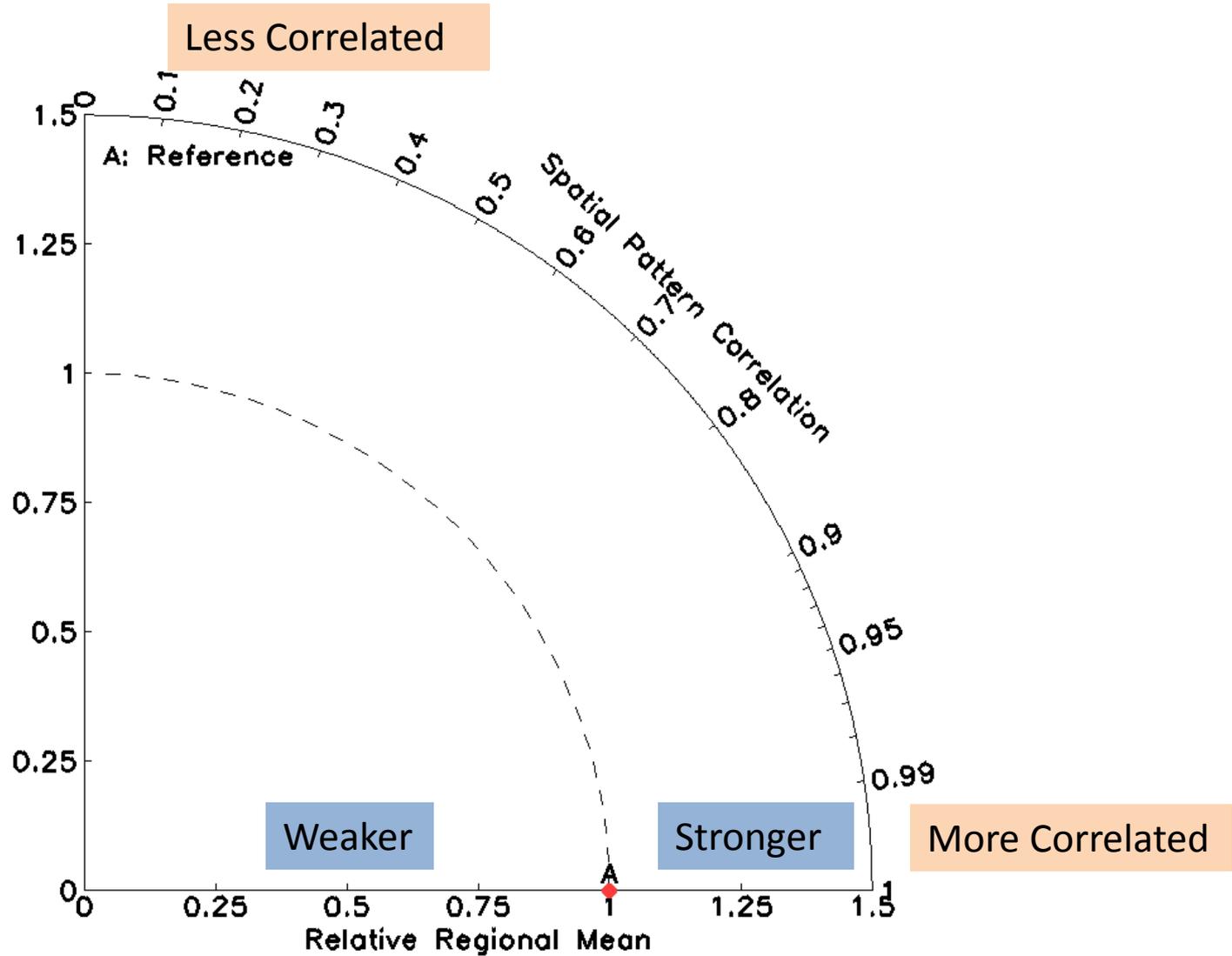
12ModelMean: comparable SW CRF, underestimates LW CRF => stronger net cooling effect
 mean bias < inter-model difference

TOA Radiative Budget Comparison: Tropical Mean

Parameters (W/m ²)	12ModelMean	CERES	12ModelMean-CERES	$\sigma(12Models-12ModelMean)$
Incoming Solar↓	400.4	399.3	1.1(0.3%)	0.6
Shortwave↑	99.5	94.6	4.9(5.2%)	5.9
Longwave↑	258.9	259.9	-1.0 (-0.4%)	4.5
Net↓	42	44.8	-2.8(-6.3%)	
Clear Shortwave↑	50.7	49.2	1.5(3.0%)	3.1
Clear Longwave↑	285.0	287.4	-2.4 (-0.8%)	3.6
Clear Net↓	64.7	62.7	-2.0(3.2%)	
Shortwave CRF	-48.8	-45.3	-3.5(7.6%)	7.7
Longwave CRF	26.2	27.5	-1.3(-4.8%)	3.8
Net CRF	-22.6	-17.9	-4.7(26.6%)	6.7

12ModelMean: overestimates SW CRF, underestimates LW CRF => stronger net cooling effect
 mean bias < inter-model difference

Taylor Diagram

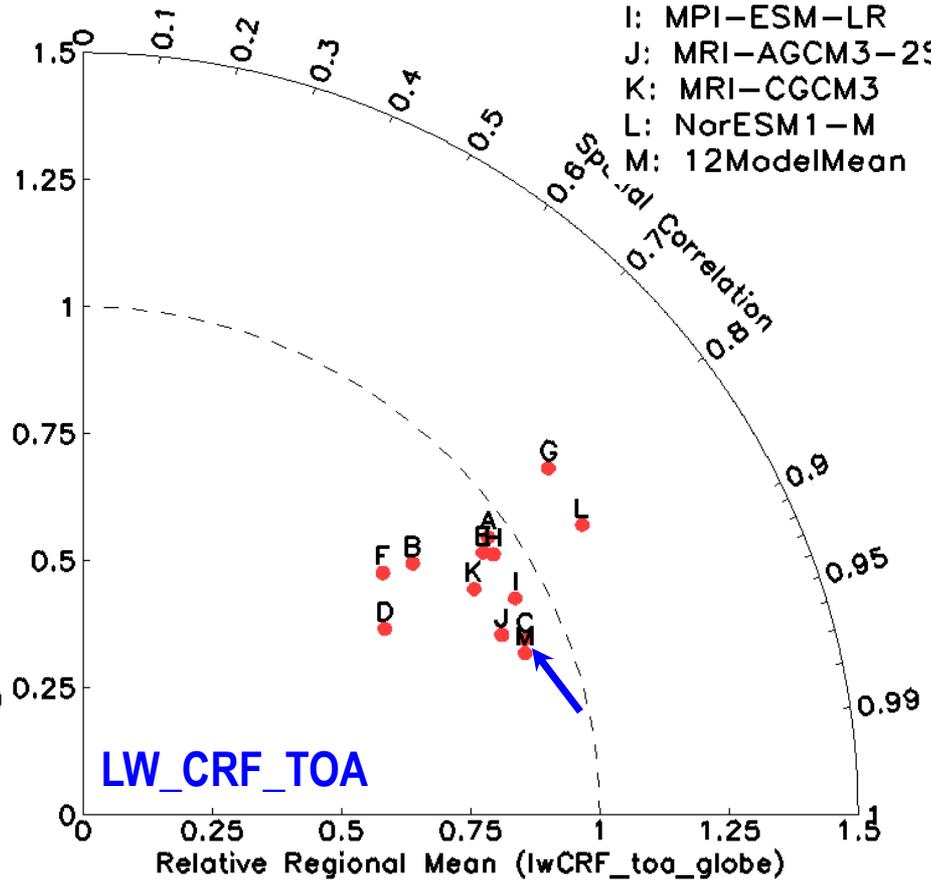
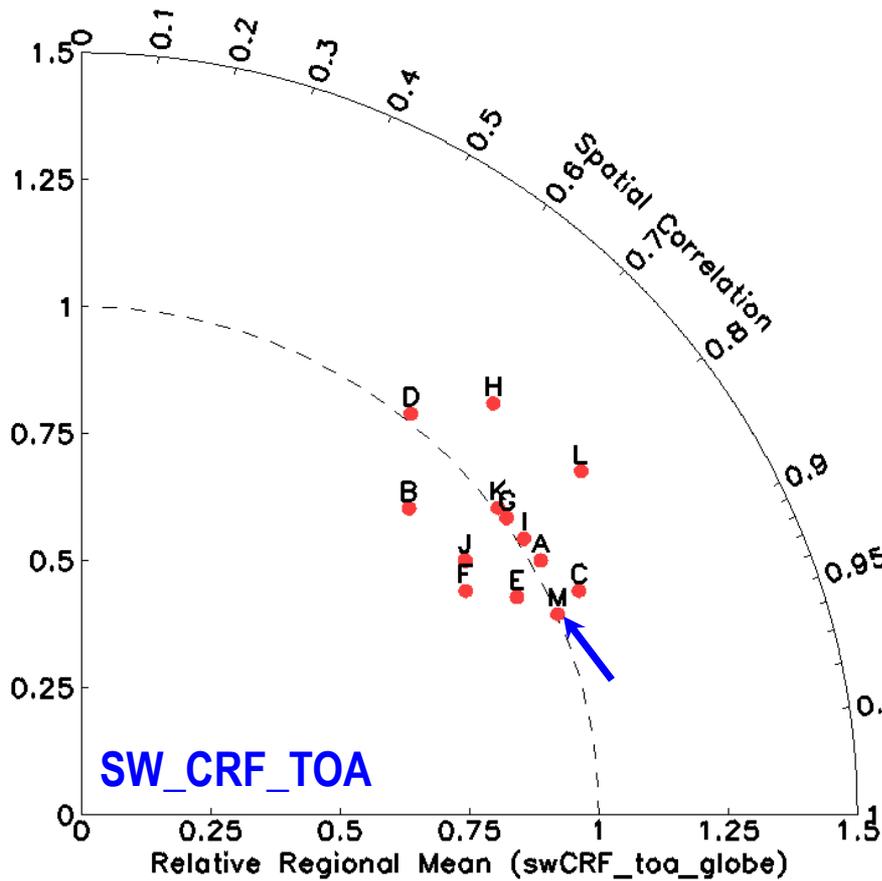


Relative regional mean (model/CERES): radius

Spatial pattern correlation(model;CERES): cosine of angle

Cloud Radiative Forcing(CRF) at TOA: Global

- A: CanAM4
- B: CNRM-CM5
- C: GFDL-HIRAM-C360
- D: GISS-E2-R
- E: HadGEM2-A
- F: Inmcm4
- G: IPSL-CM5A-LR
- H: MIROC5
- I: MPI-ESM-LR
- J: MRI-AGCM3-2S
- K: MRI-CGCM3
- L: NorESM1-M
- M: 12ModelMean



Global Mean:

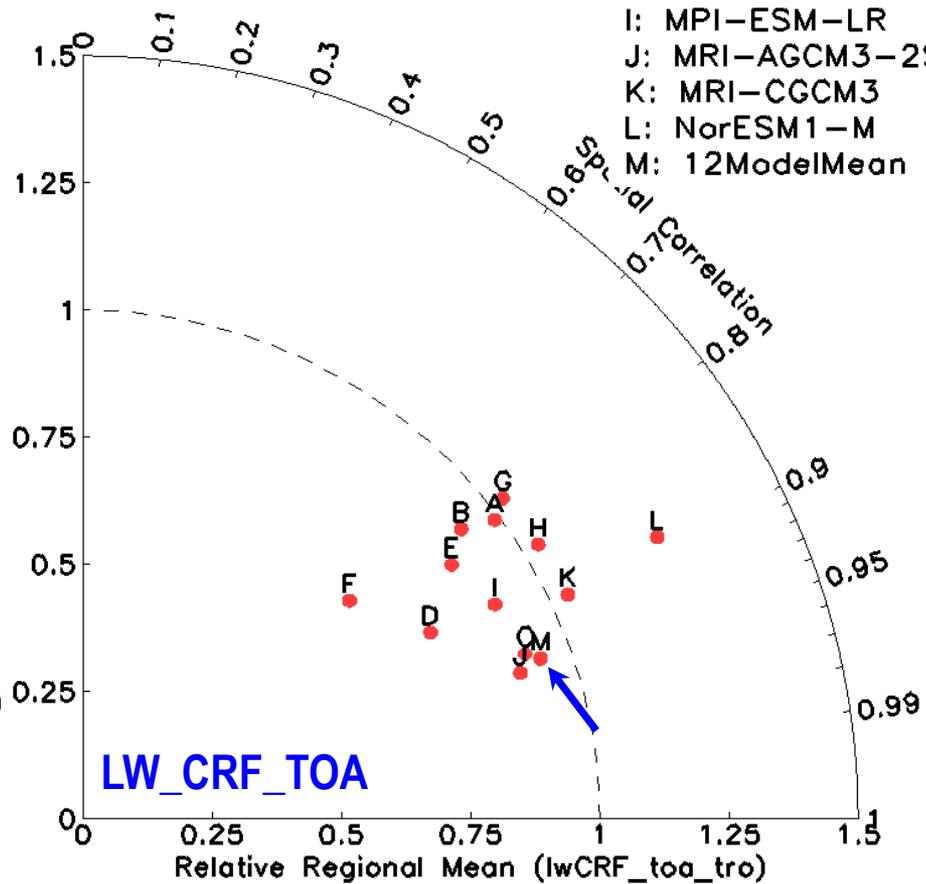
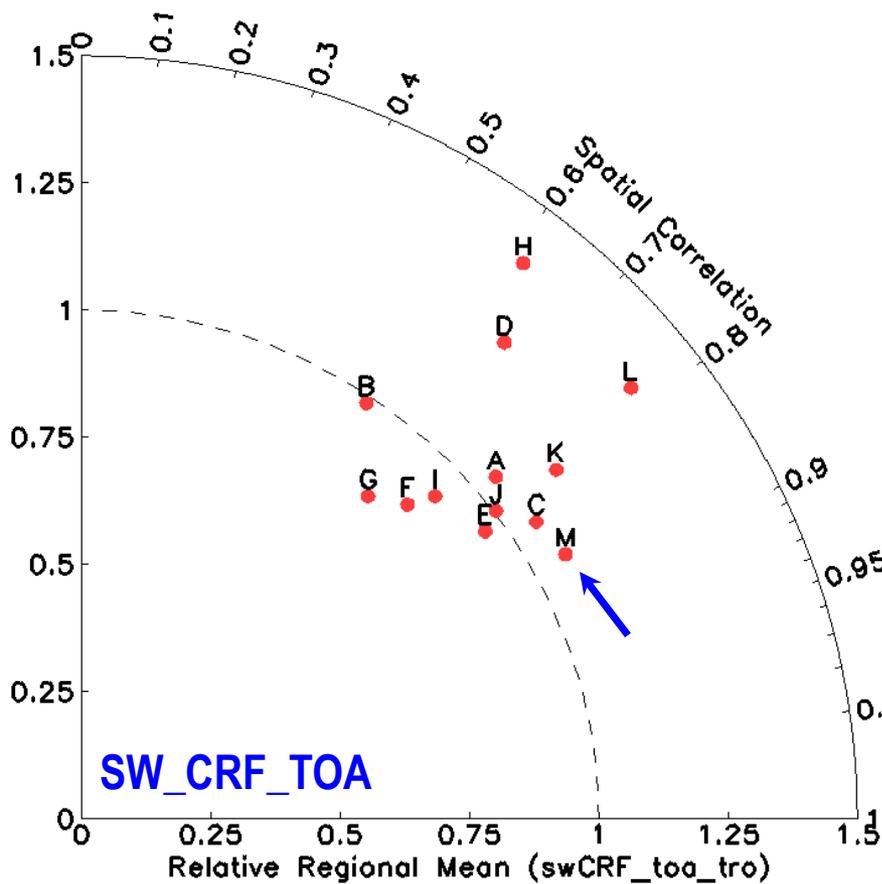
SW_CRF(cooling): 5 Models comparable; 3 Models > CERES; 4 Models < CERES

LW_CRF(warming): 10 Models < CERES; **Net_CRF(cooling):** 8 Models > CERES

Spatial Pattern: LW_CRF > SW_CRF

Cloud Radiative Forcing(CRF) at TOA: Tropics

- A: CanAM4
- B: CNRM-CM5
- C: GFDL-HIRAM-C360
- D: GISS-E2-R
- E: HadGEM2-A
- F: Inmcm4
- G: IPSL-CM5A-LR
- H: MIROC5
- I: MPI-ESM-LR
- J: MRI-AGCM3-2S
- K: MRI-CGCM3
- L: NorESM1-M
- M: 12ModelMean



Tropical Mean:

SW_CRF(cooling): 8 Models \geq CERES

LW_CRF(warming): 8 Models $<$ CERES; Net_CRF(cooling): 10 Models $>$ CERES

Spatial Pattern: LW_CRF $>$ SW_CRF

CRF at TOA: 12Models vs. CERES

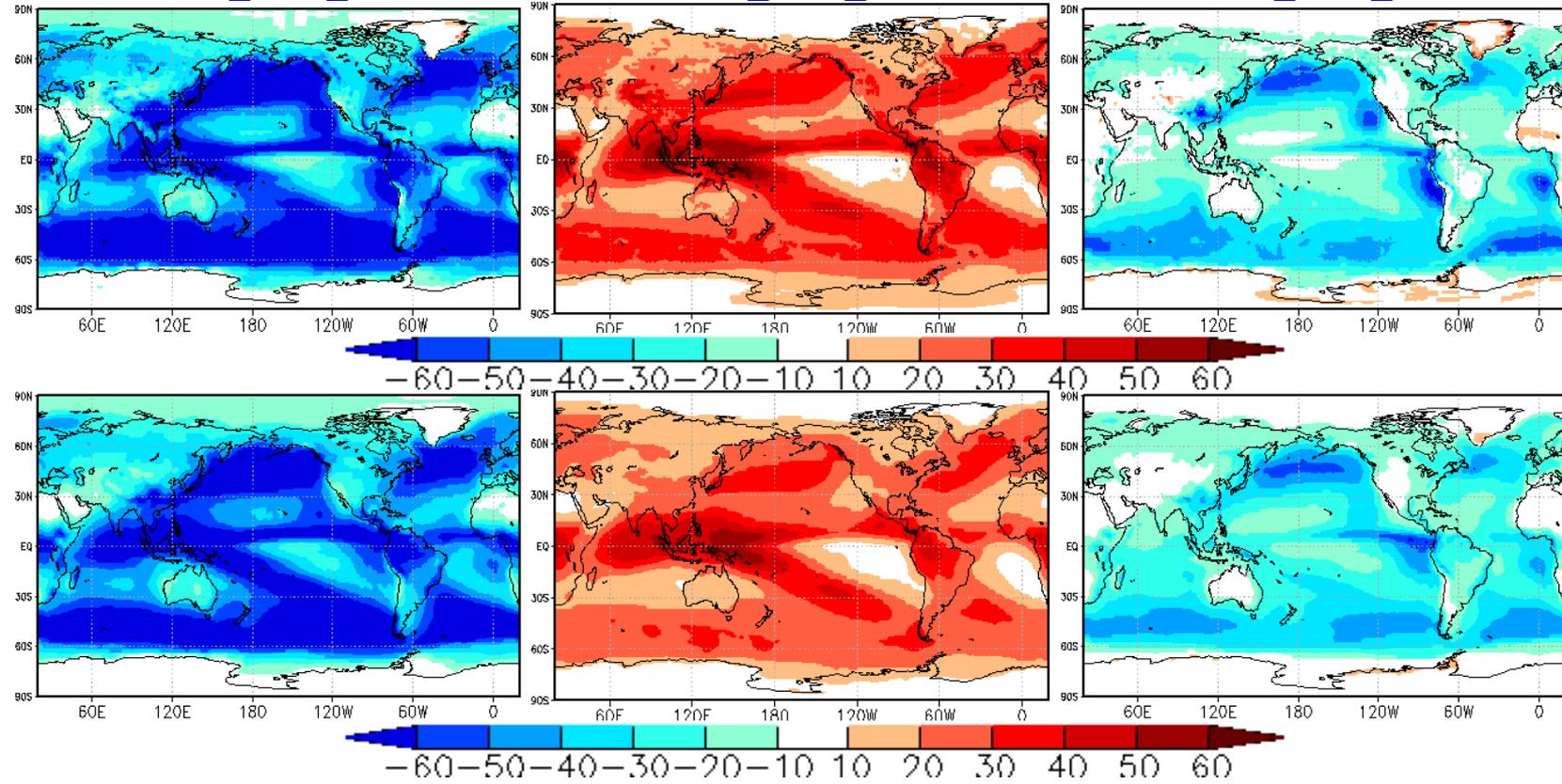
SW_CRF_TOA

LW_CRF_TOA

Net_CRF_TOA

CERES

12ModelMean



CRF at TOA: 12Models vs. CERES

SW_CRF_TOA

LW_CRF_TOA

Net_CRF_TOA

CERES

12ModelMean
-CERES

-60 -50 -40 -30 -20 -10 10 20 30 40 50 60

-18 -15 -12 -9 -6 -3 3 6 9 12 15 18

Stronger SW cooling and LW warming over trade wind regions and western tropical Indian Ocean: common model bias
Weaker SW cooling over eastern subtropical ocean basins: common model bias and inter-model differences

CRF at TOA: 12Models vs. CERES

SW_CRF_TOA

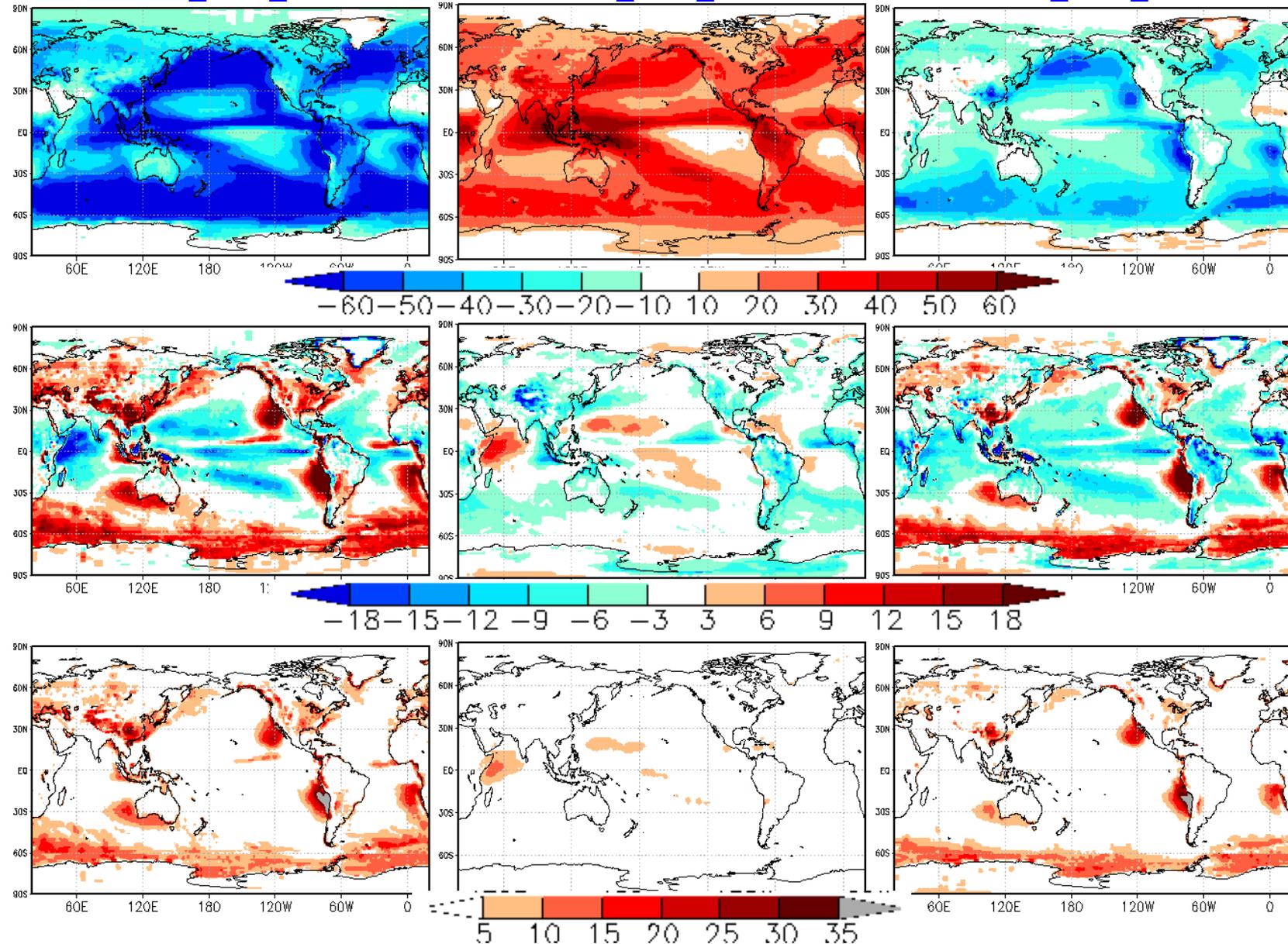
LW_CRF_TOA

Net_CRF_TOA

CERES

12ModelMean
-CERES

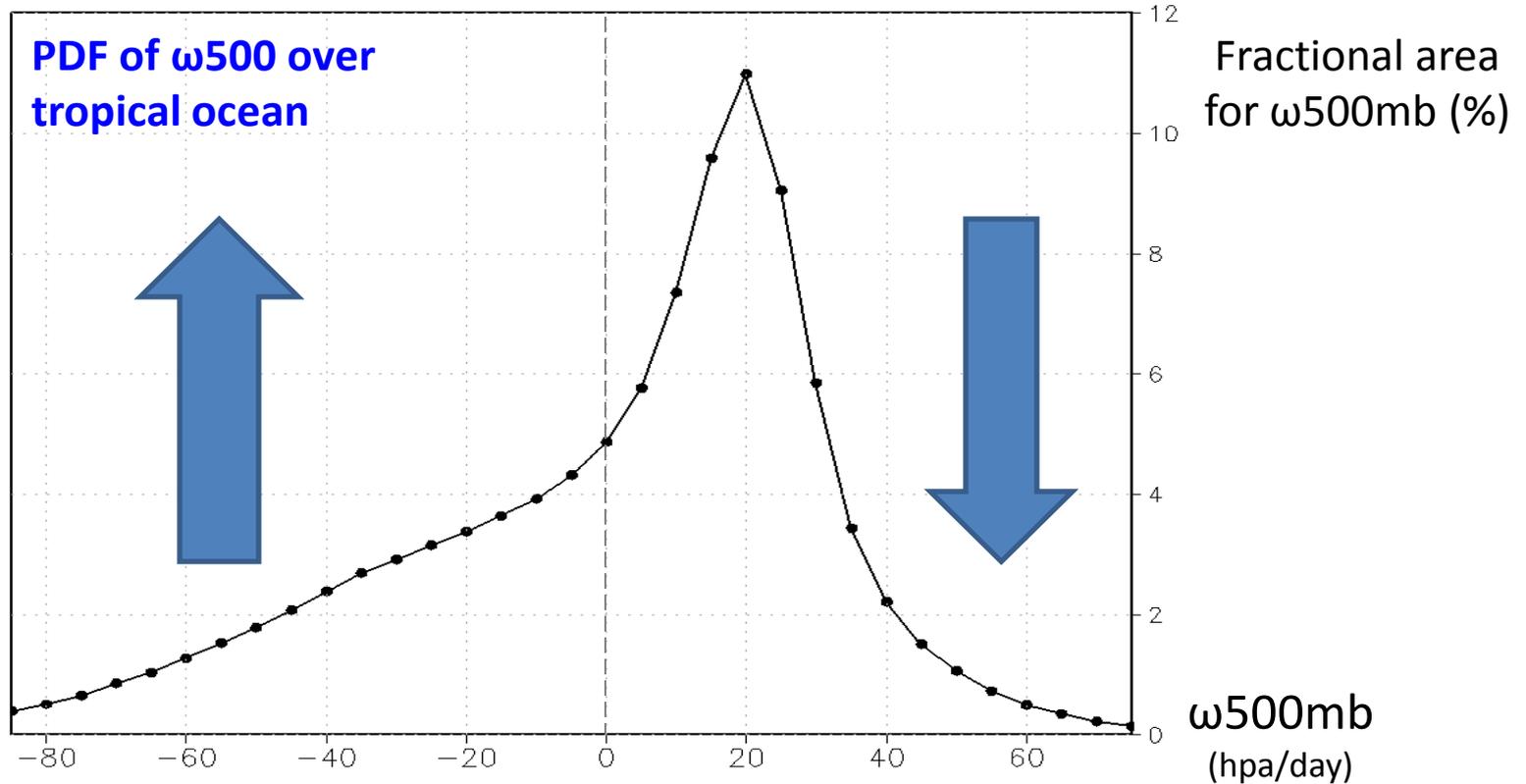
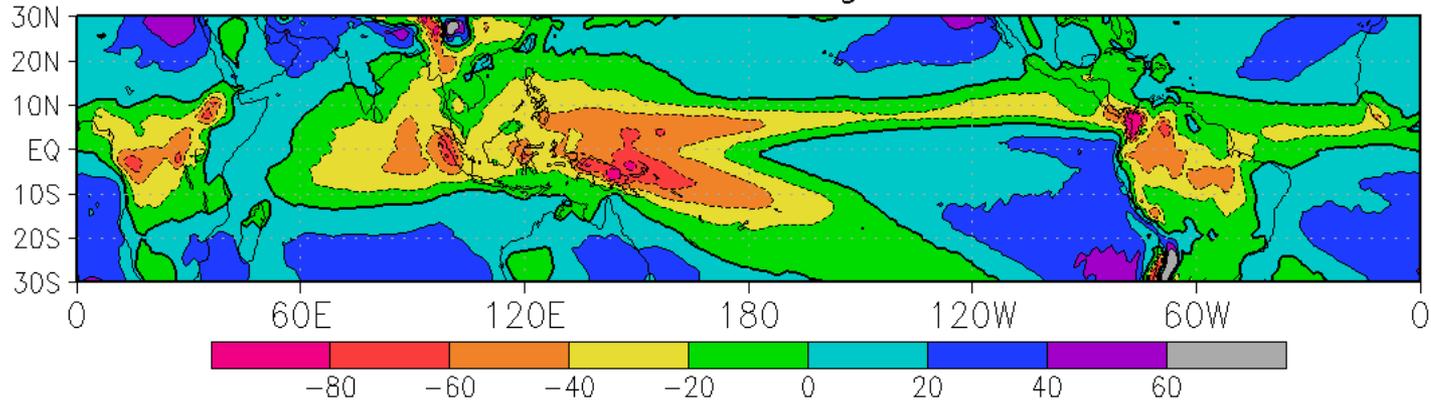
$\sigma(12Models-12ModelMean)$



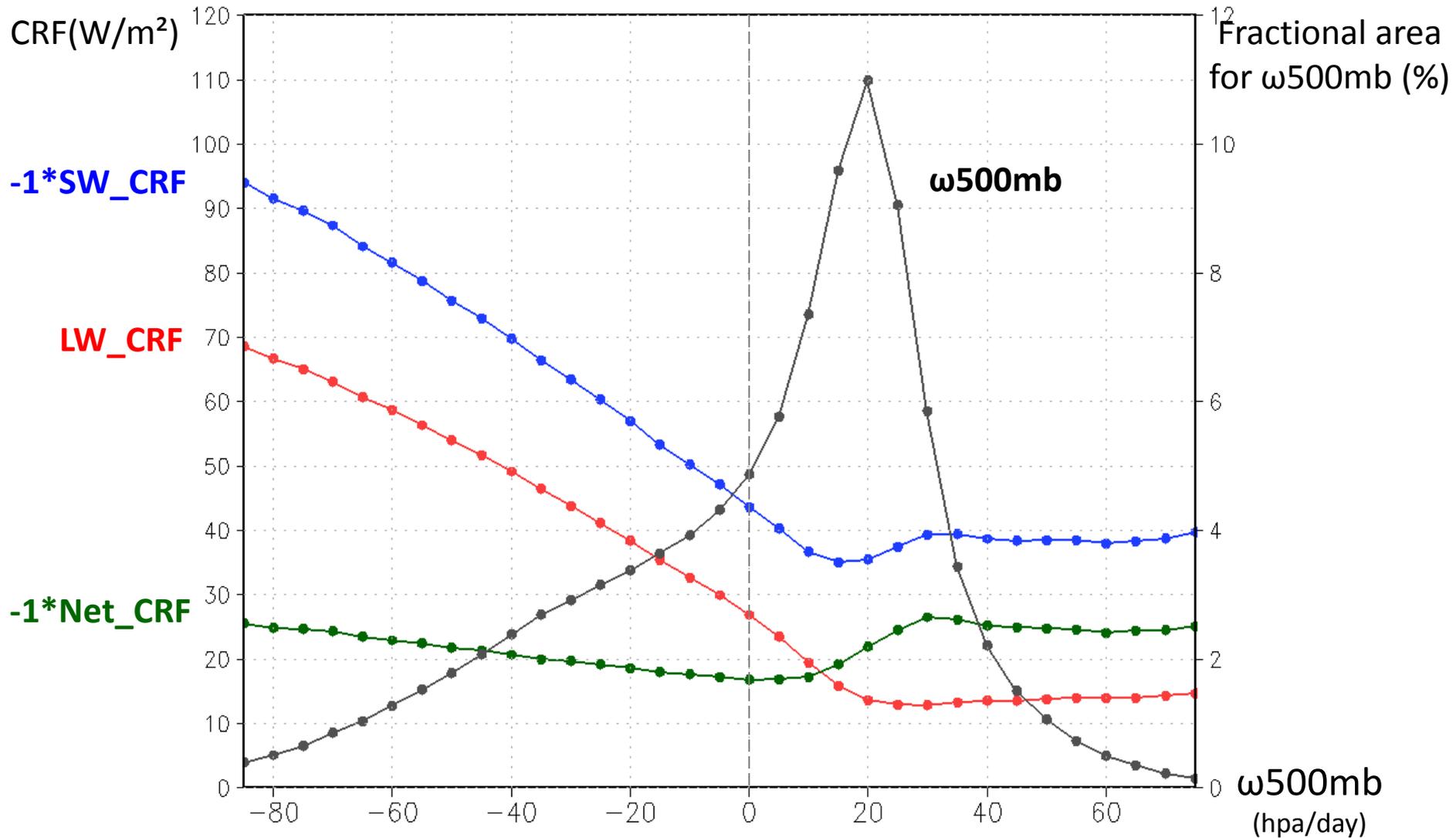
Stronger SW cooling and LW warming over trade wind regions and western tropical Indian Ocean: common model bias
Weaker SW cooling over eastern subtropical ocean basins: common model bias and inter-model differences

ERA Interim: Annual Climatology of ω_{500}

Annual Clim Omega500mb



Composites of TOA_CRF in Different Circulation Regimes CERES; Tropical Ocean

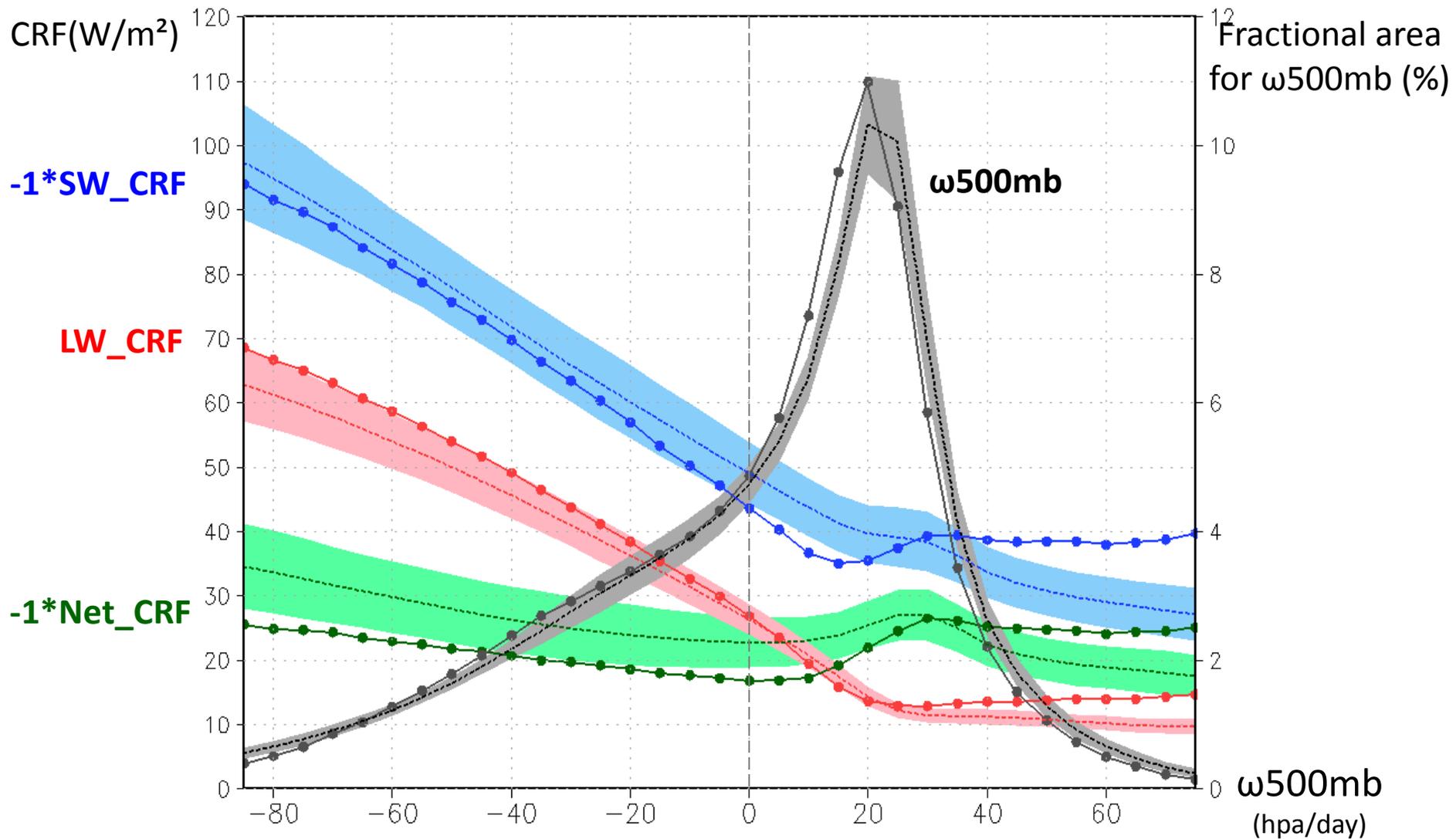


$\omega=20$ (moderate subsidence area): occupies the largest fractional area

$\omega < 10$ (convective and weak subsidence area): both SW CRF and LW CRF decrease with ω , with SW cooling dominating;

$\omega > 30$ (strong subsidence area): relatively constant

Composites of TOA_CRF in Different Circulation Regimes CMIP5 vs. CERES; Tropical Ocean



ω < -10 (convective area):

-10 < ω < 25 (weak subsidence area):

ω > 30 (strong subsidence area):

slightly stronger SW CRF,

stronger SW CRF,

weaker SW CRF,

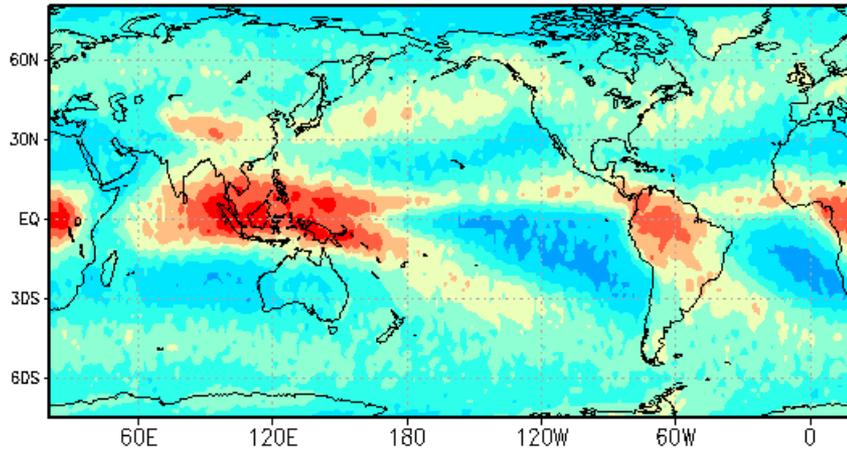
weaker LW CRF

stronger LW CRF

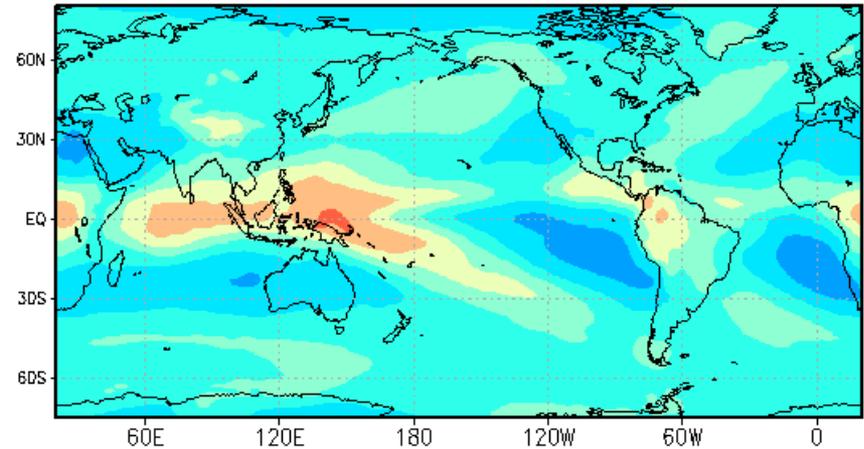
weaker LW CRF

High Cloud: 6ModelMean vs GOCCP (Annual2007-2008)

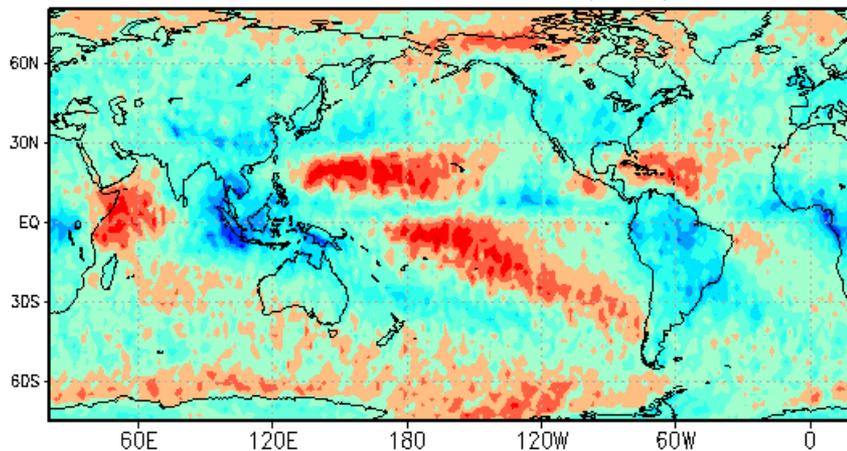
GOCCP (TroMean: 34%)



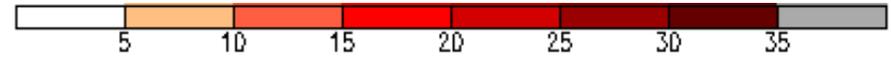
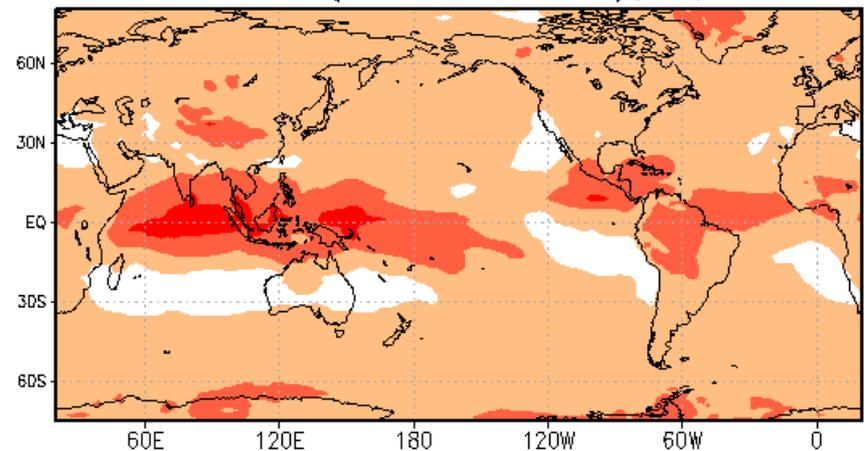
6ModelMean (29%)



6ModelMean-GOCCP (-5%)



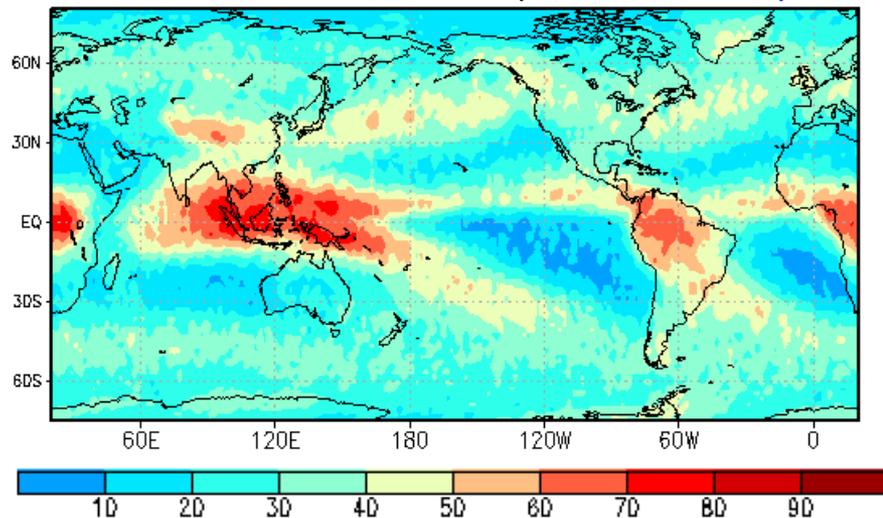
std(6Models-6ModelMean) (6%)



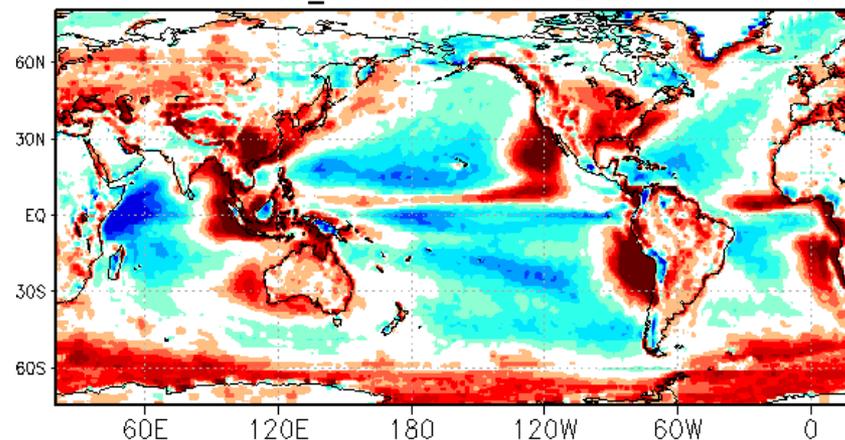
Stronger convection: trade wind area, western tropical Indian Ocean – common model bias
Weaker convection: maritime continent

High Cloud: 6ModelMean vs GOCCP (Annual2007-2008)

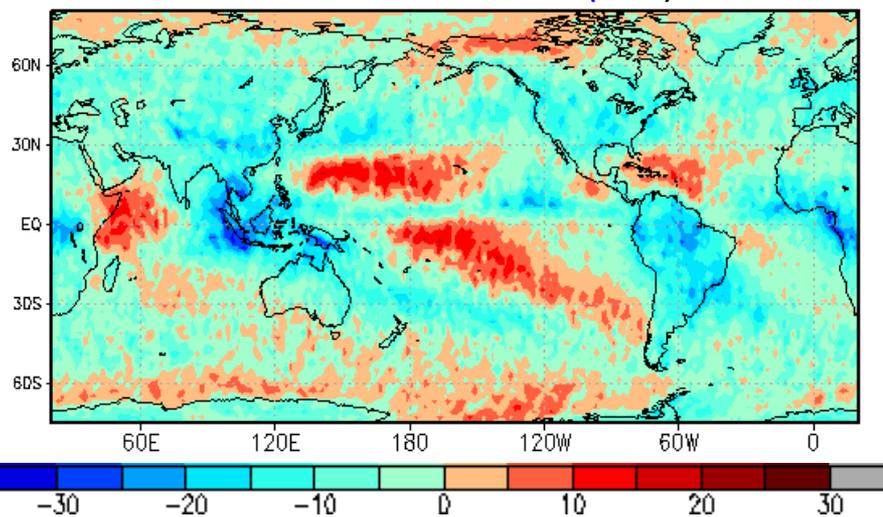
GOCCP (TroMean: 34%)



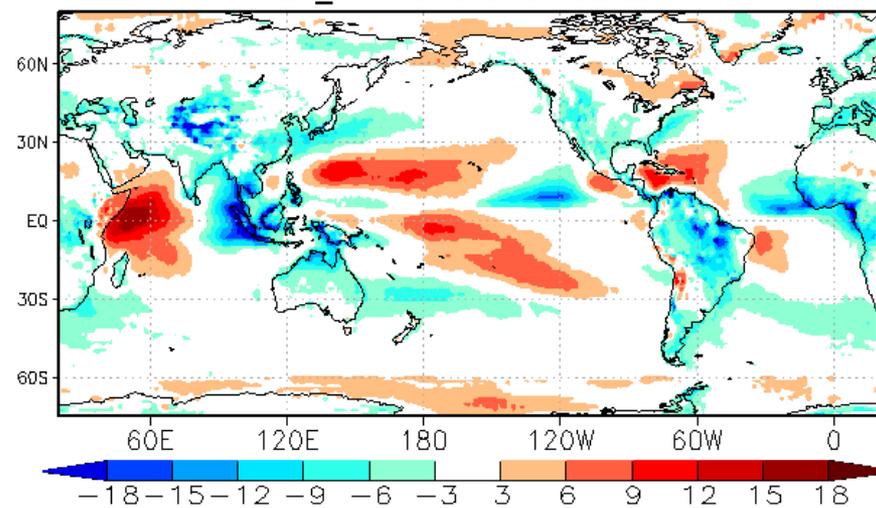
SW_CRF 6ModelMean-CERES



6ModelMean-GOCCP (-5%)



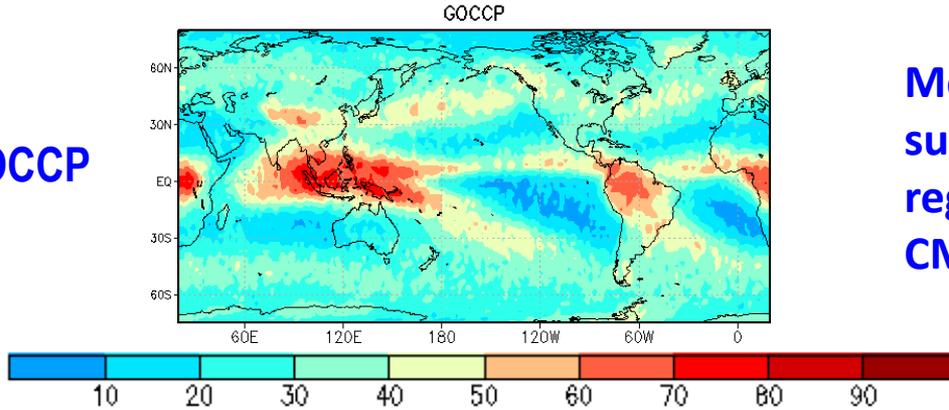
LW_CRF 6ModelMean-CERES



Stronger (weaker) tropical convection: enhanced (weakened) SW cooling and LW warming

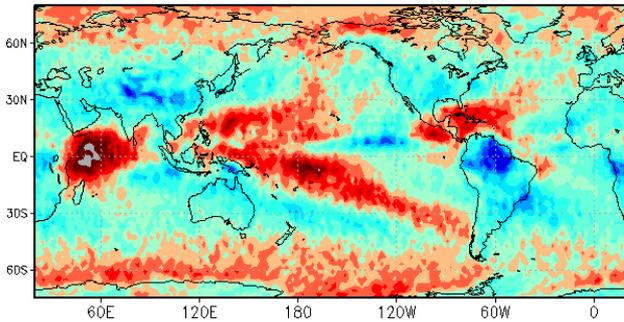
High Cloud: CMIP5 - GOCCP Annual 2007-2008

GOCCP

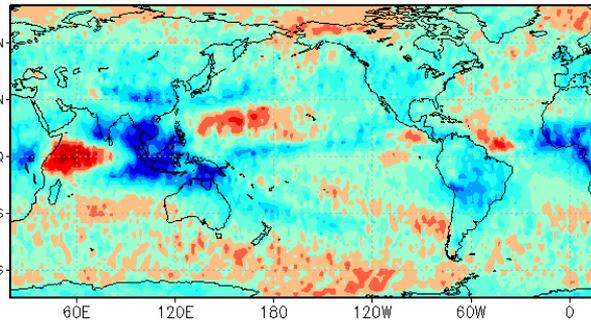


More high cloud over
subtropical trade wind
regions is common in
CMIP5 models

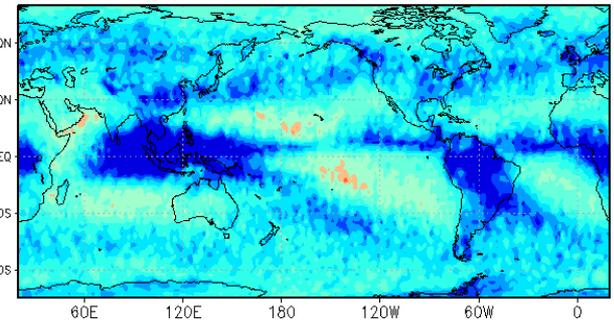
CanAM4



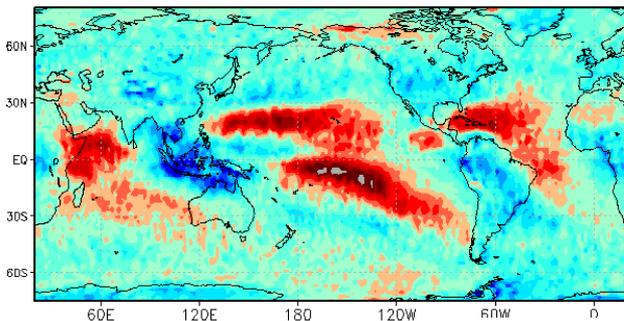
HadGEM2-A



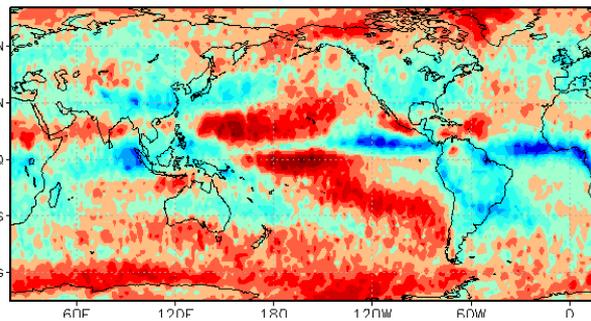
MIROC5



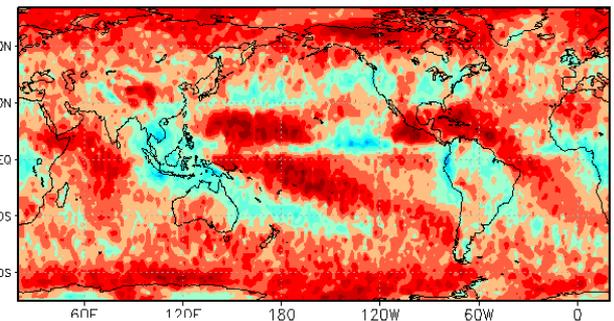
CNRM-CM5



IPSL-CM5A-LR

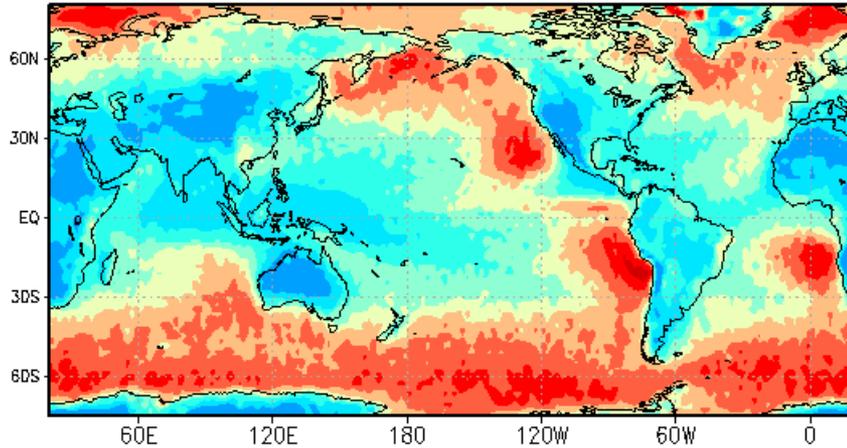


MPI-ESM-LR

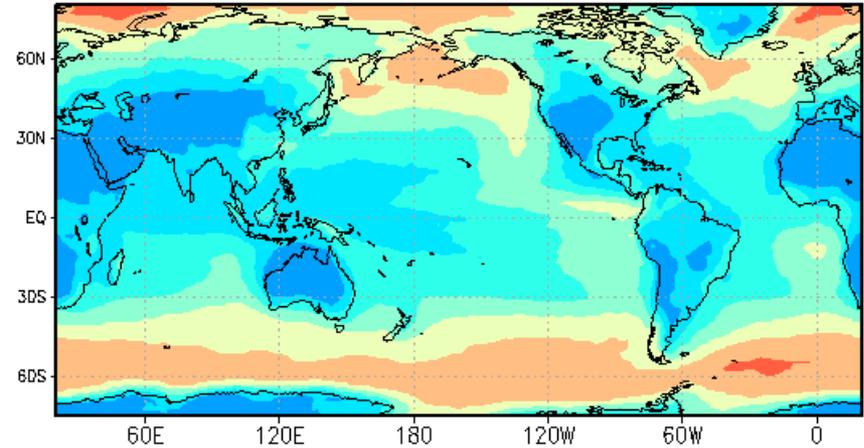


Low Cloud: 6ModelMean vs GOCCP (Annual 2007-2008)

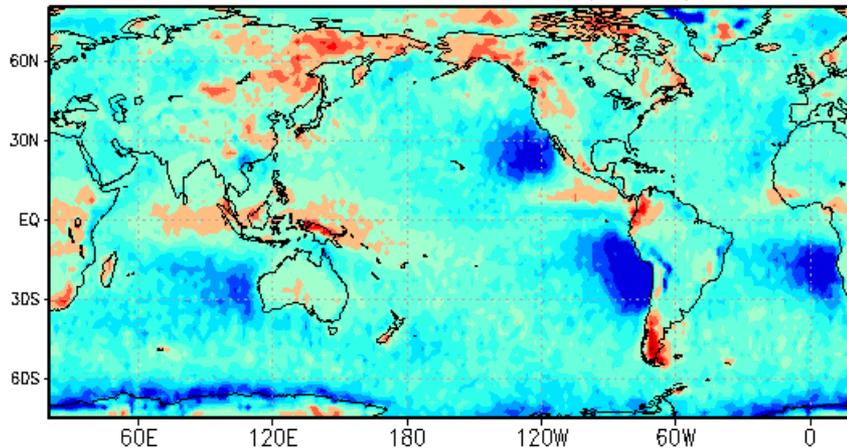
GOCCP (TroMean: 30%)



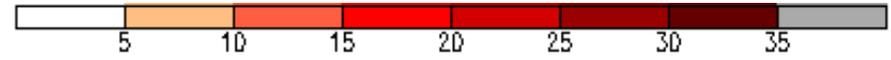
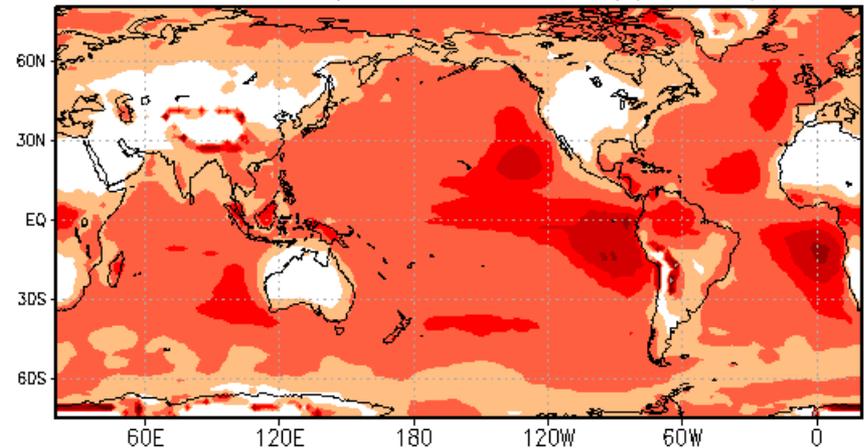
6ModelMean (20%)



6ModelMean-GOCCP (-10%)



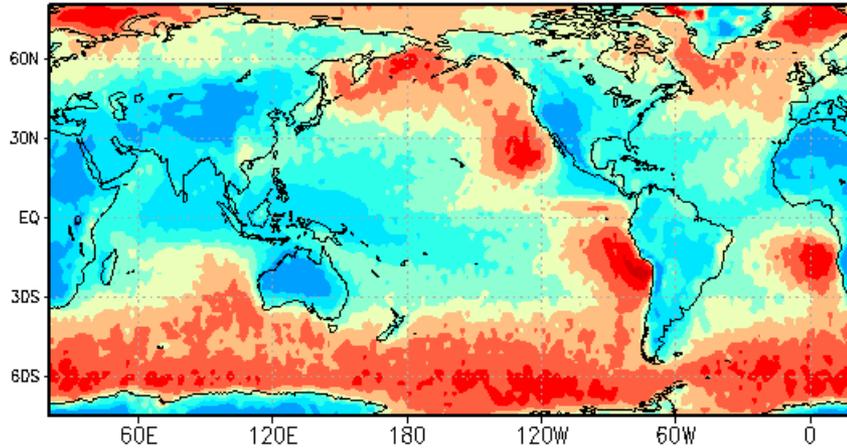
std(6Models-6ModelMean) (10.4%)



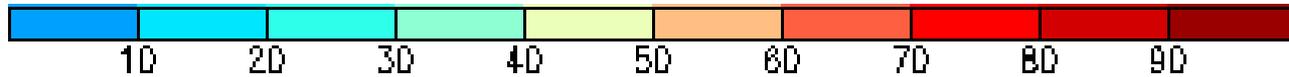
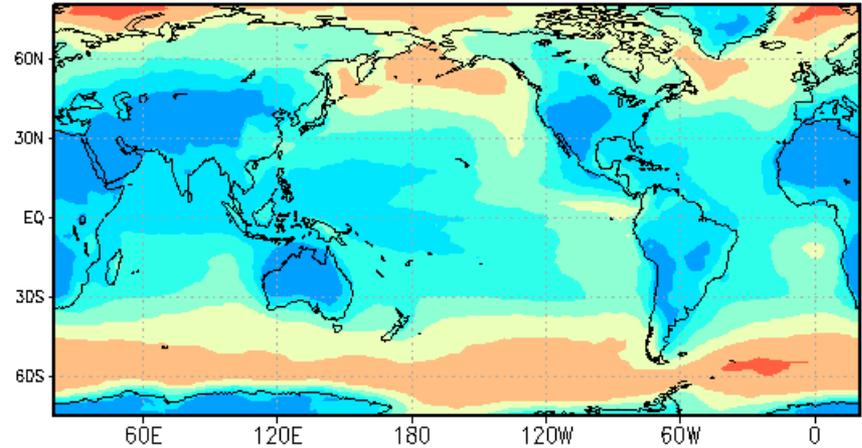
**East side of subtropical ocean basins:
rather weak low-level clouds => weaker TOA SW cooling in CMIP5**

Low Cloud: 6ModelMean vs GOCCP (Annual 2007-2008)

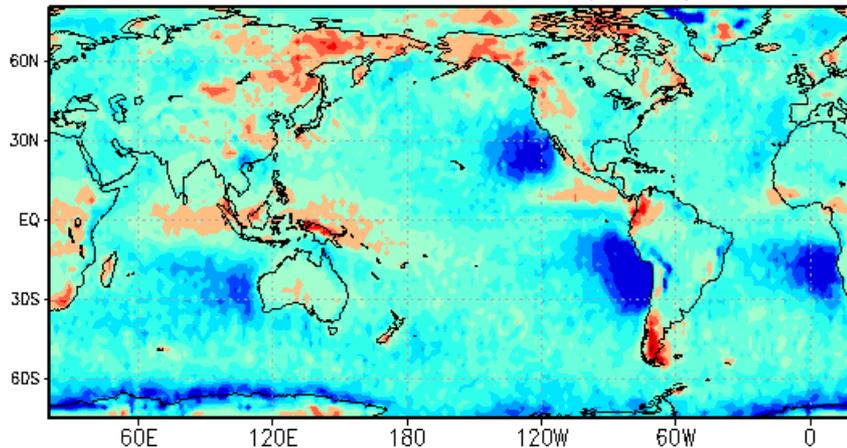
GOCCP (TroMean: 30%)



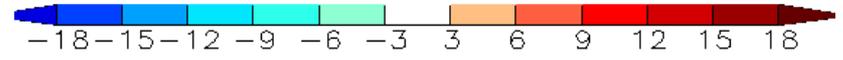
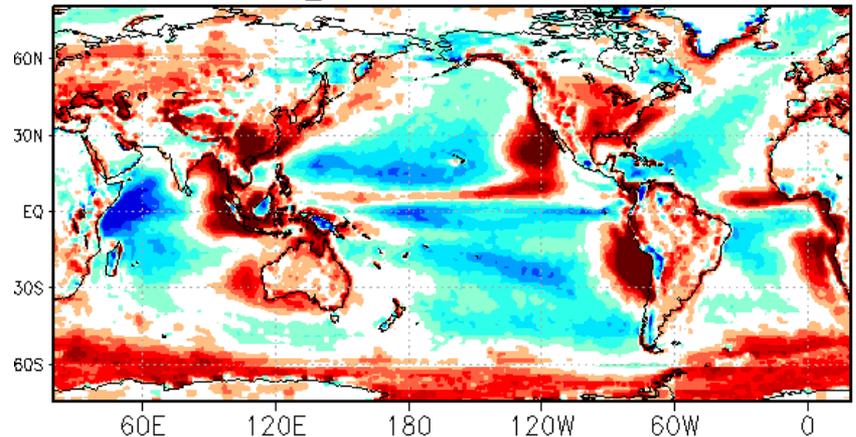
6ModelMean (20%)



6ModelMean-GOCCP (-10%)



SW_CRF 6ModelMean-CERES



**East side of subtropical ocean basins:
rather weak low-level clouds => weaker TOA SW cooling in CMIP5**

Conclusions

- The 12 CMIP5 model mean overestimates TOA shortwave (SW) cooling and underestimates longwave (LW) warming, and shows stronger net cooling effect by clouds.
- The multi-model mean difference from CERES EBAF is smaller than inter-model difference.
- The regional mean cloud radiative effects in the tropics in CMIP5 is a result of compensating errors over different regions
 - Deep convective area:
 - Large inter-model differences; weaker TOA SW cooling and LW warming effects, due to weaker deep convection
 - Trade wind area:
 - **Common model deficiency**: stronger TOA SW cooling and LW warming, due to enhanced tropical convection and high clouds there
 - East side of subtropical ocean basins:
 - Large inter-model differences; Considerably weaker SW cooling, due to lack of sufficient low clouds there