Understanding Radiative Response of Stratocumulus Regime in five CMIP5 Climate Models

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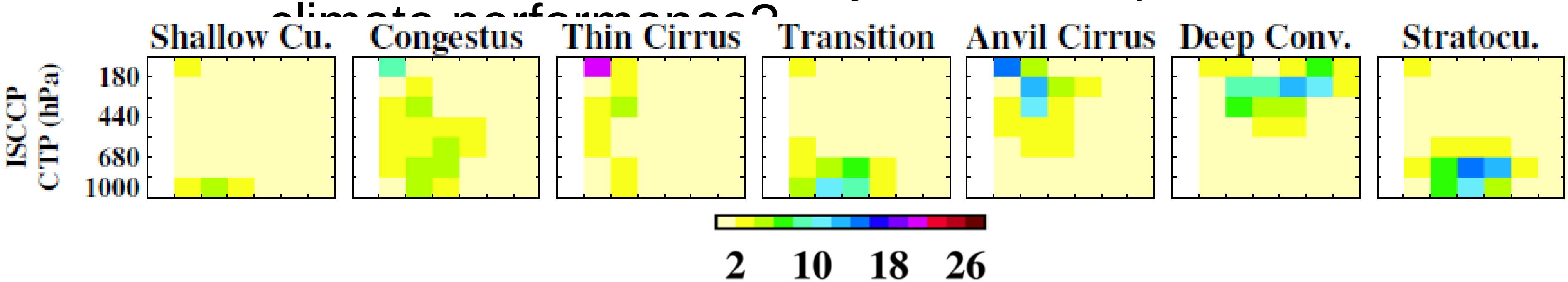
A question investigated in the previous meeting

Q: Do the magnitudes of the change in frequency of occurrence/radiative property of cloud regimes in different models have any relationship to their control climate performance?

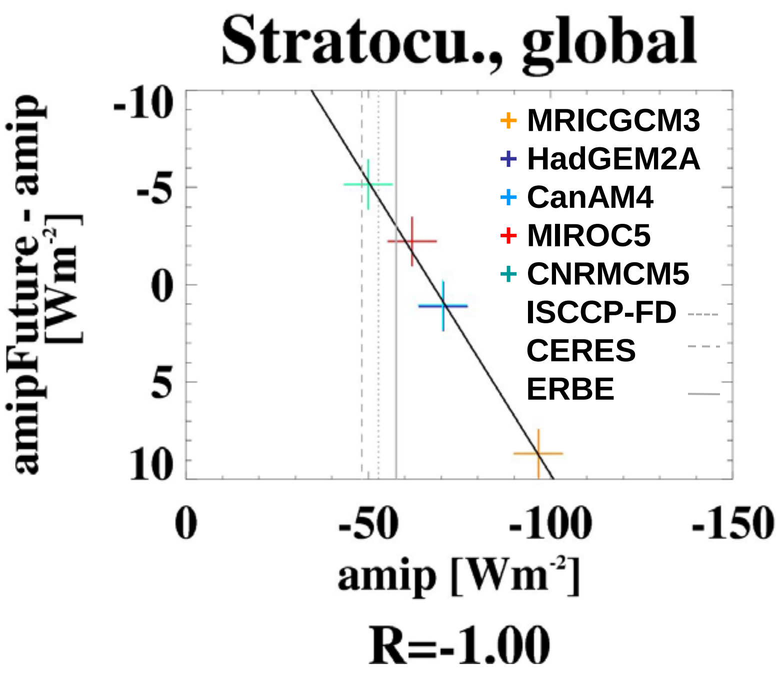


Cloud regime analysis based on Williams and Webb (2009) are applied to daily outputs of amip run & amipFuture run.

- 5 models (HadGEM2-A, CanAM4, CNRM-CM5, MIROC5, MRI-CGCM3)
- A cloud regime is assigned for each grid data. Using a vector of (In-cloud albedo, cloud top pressure, total cloud cover) from the ISCCP-simulator and using a normalised minimum root-sum-square measure of distance to corresponding observed vectors, a regime with the closest distance is chosen.
- Frequency of occurrence of each regime, average cloud radiative effects (CREs) of each regime are estimated.
- For each variable, correlations of 5 model values in amip run and the changes in amipFuture run are taken.
- Observations: Daily ISCCP D1, ISCCP-FD, ERBE, CERES
- Period: 1985-1990, 1994-2007

A: No significant correlation is found, except stratocumulus regime of its in-regime net CRE.

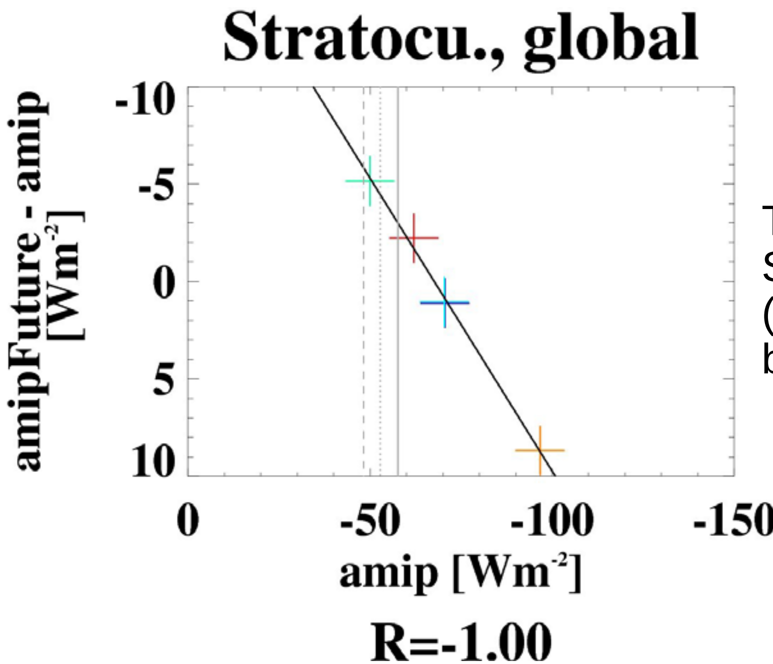
In-regime NCRE



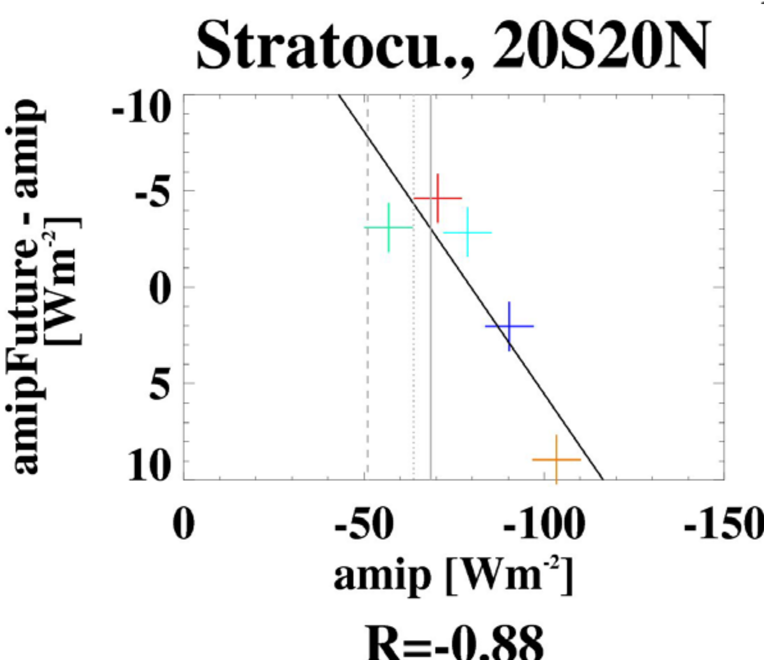
- The magnitudes of the change in in-regime net CRE of stratocumulus regimes in different models have significant correlation to their control climate performance.

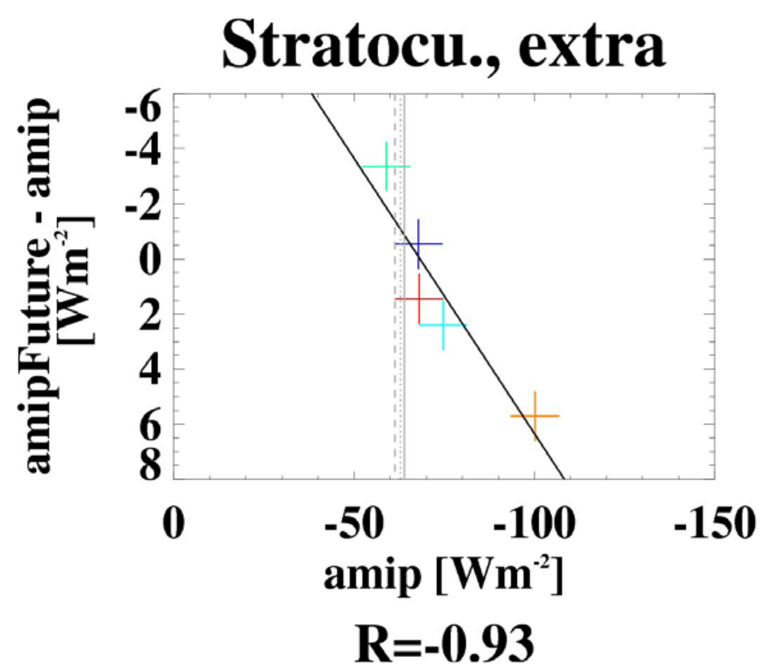
In-regime NCRE

+ MRICGCM3
+ HadGEM2A
+ CanAM4
+ MIROC5
+ CNRMCM5
ISCCP-FD
CERES
ERBE



These correlations are found both in Shortwave (SW) CRE and Longwave (LW) CRE,
but SW CRE dominates in magnitude.

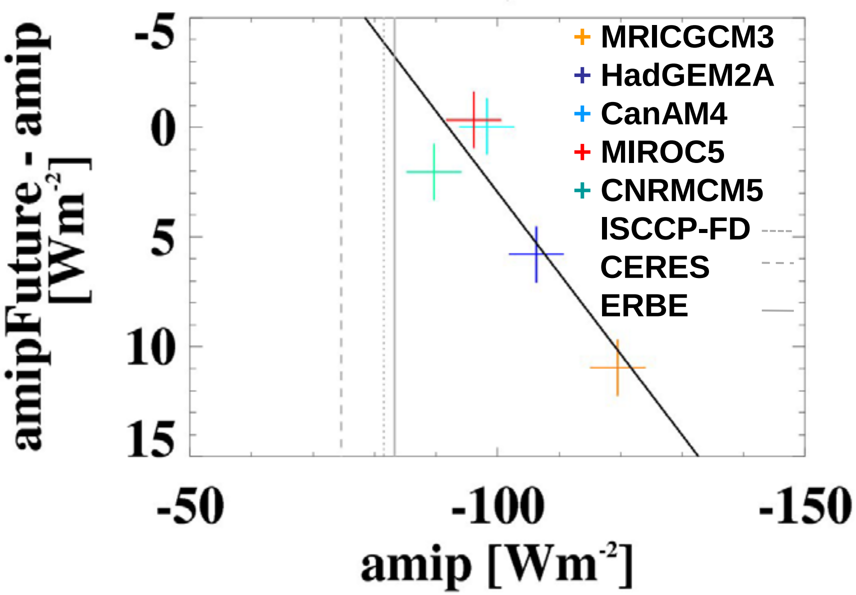




Stratocumulus regime [20S,20N]
in-regime SW CRE and in-regime cloud albedo

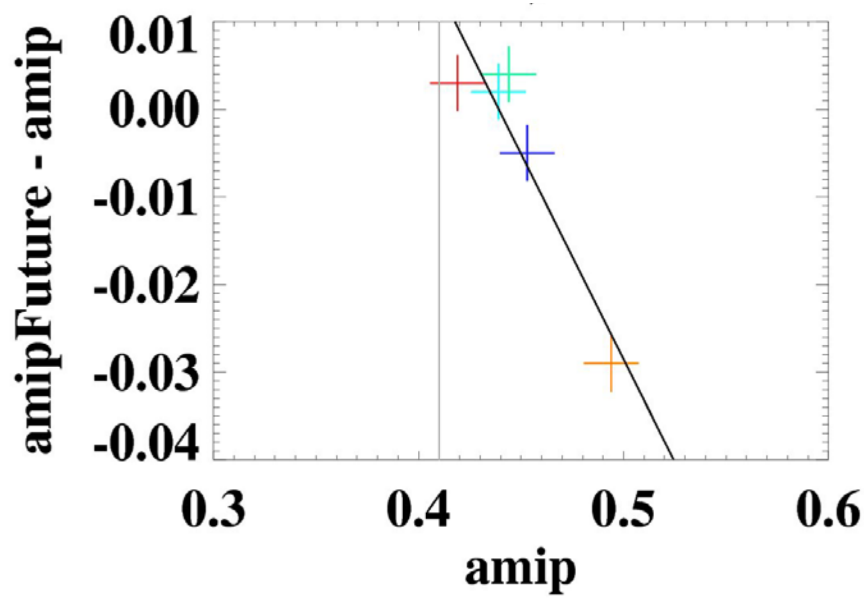
ISCCP-simulator cloud cover: cltisccp
ISCCP-simulator in-cloud albedo: albisccp
In-regime cloud albedo: cltisccp x albisccp

in-regime SW CRE



R=-0.89

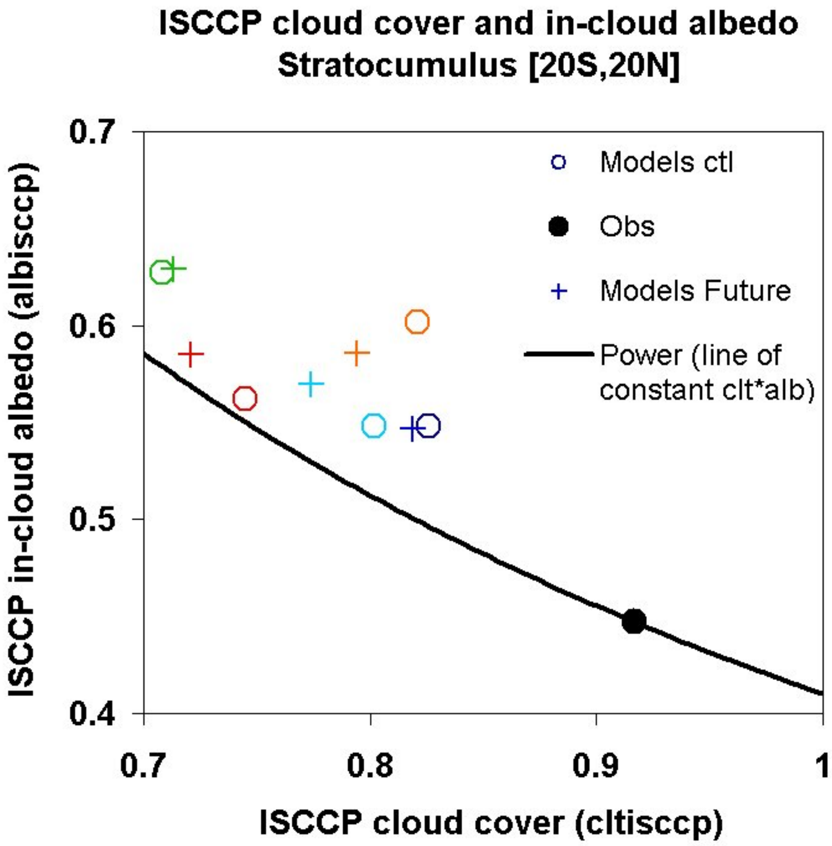
ISCCP in-regime albedo

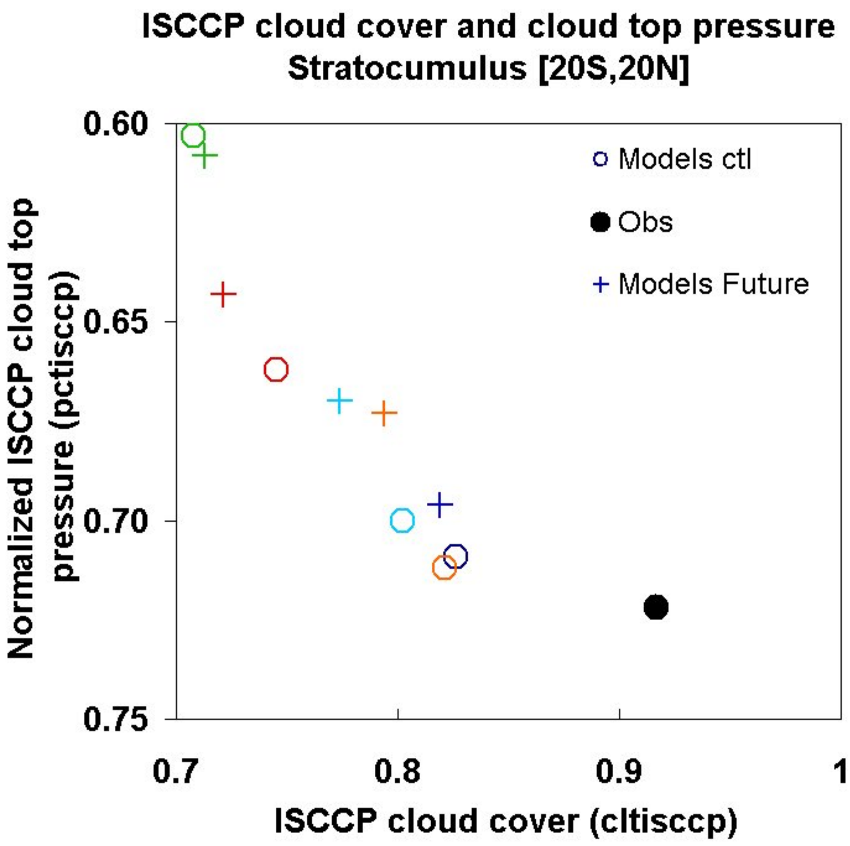


R=-0.93

A product out of cltisccp x albisccp roughly reproduces the corresponding correlation found in in-regime SW CRE.

Stratocumulus regime [20S,20N] cloud properties





Models' stratocumulus regimes are too small in coverage, too bright in albedo, too high in cloud top height. (Models align on a curve in a plot of cloud cover, cloud top pressure.

In models whose in-regime SW CRE agree better with observations, representations of individual aspect are worse.

Which cloud property controls in-regime SW CRE of stratocumulus?

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Correlated properties	Correlation coefficient
In-regime SW CRE, cltisccp	-0.81
In-regime SW CRE, albisccp	0.06
Δ(In-regime SW CRE), Δcltisccp	-0.06
Δ(In-regime SW CRE), Δalbisccp	-0.95

- The inter-model difference is correlated to cloud cover in the control climate,
- but that of future response is correlated to in-cloud albedo.
- Is there any process that cloud cover in the control climate affect the albedo response?

What controls inter-model difference of in-cloud albedo change?

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- In-cloud albedo decrease in higher sensitivity models which show larger weakening of in-regime SW CRE.
- However, liquid water path (LWP) and in-cloud LWP increases in all models.

models	Change in ISCCP in-cloud albedo	Change in in-cloud LWP [kgm^{-2}]
MRICGCM3	-0.016	2.34E-03
HadGEM2	-0.001	7.93E-03
CanAM4	0.022	3.89E-03
MIROC5	0.023	4.52E-03
CNRMCM5	0.002	1.13E-03

Stephens (1978)

$$c \cdot \tau \approx \frac{3}{2}\frac{W}{r_e}$$

c :cloud cover

τ :optical thickness

W :liquid water path

r_e :cloud effective radius

$$\Delta(c \cdot \tau) = \frac{3}{2}\left\{\frac{1}{r_e}\Delta W \cdot + W \cdot \Delta\left(\frac{1}{r_e}\right) + \Delta W \cdot \Delta\left(\frac{1}{r_e}\right)\right\}$$

To have smaller in-cloud albedo with larger in cloud LWP in warming climate, cloud effective radius has to be larger in amipFuture.

How effective radius can increase differently (How cloud condensation nuclei can decrease differently) in different models?

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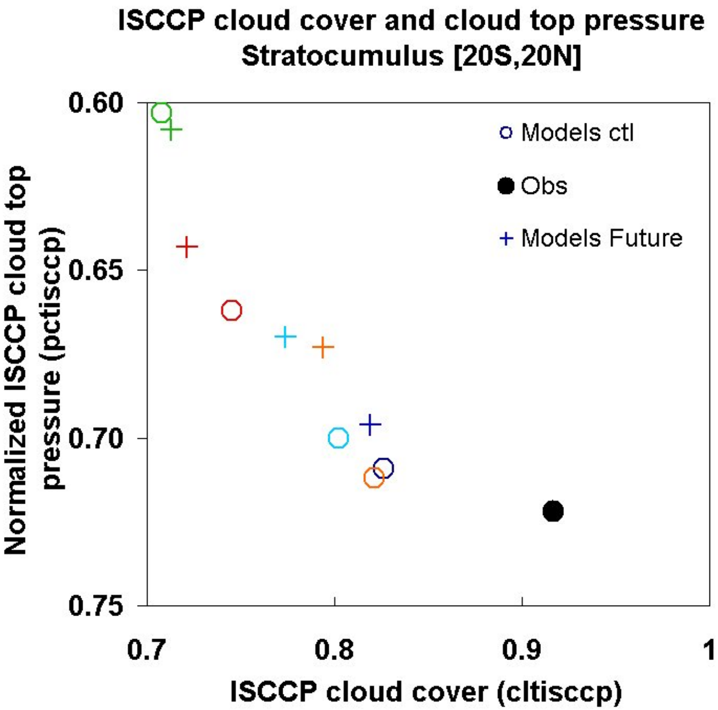
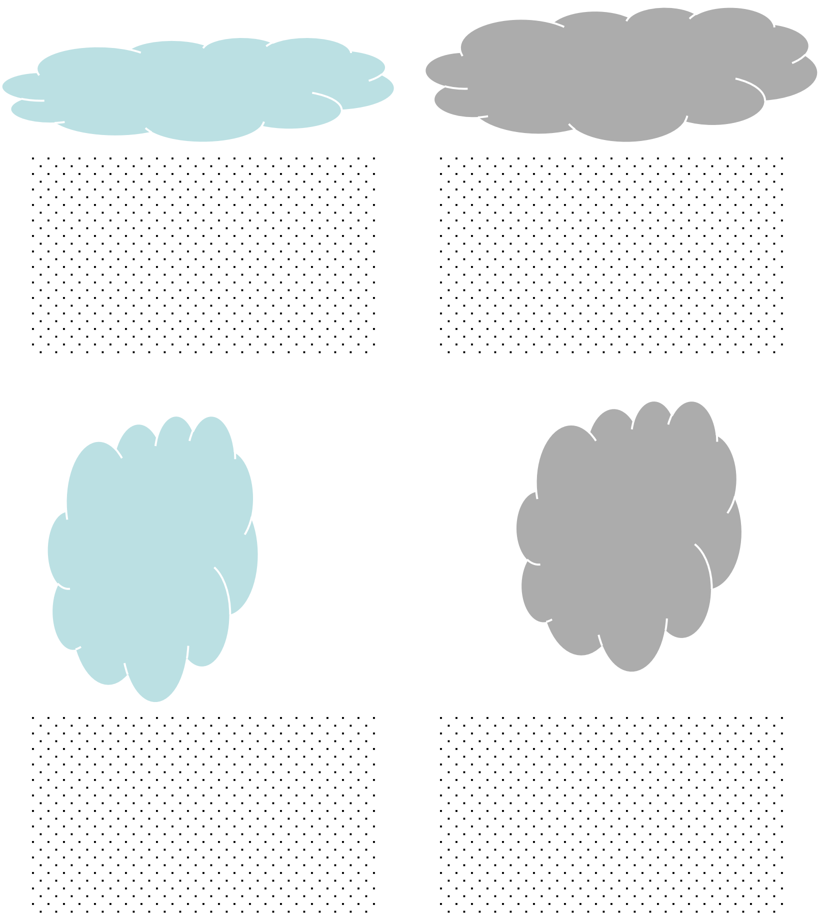
- Aerosol emissions are kept the same in amip and amipFuture.
- In warming climate, LWP and precipitation increase in all models.

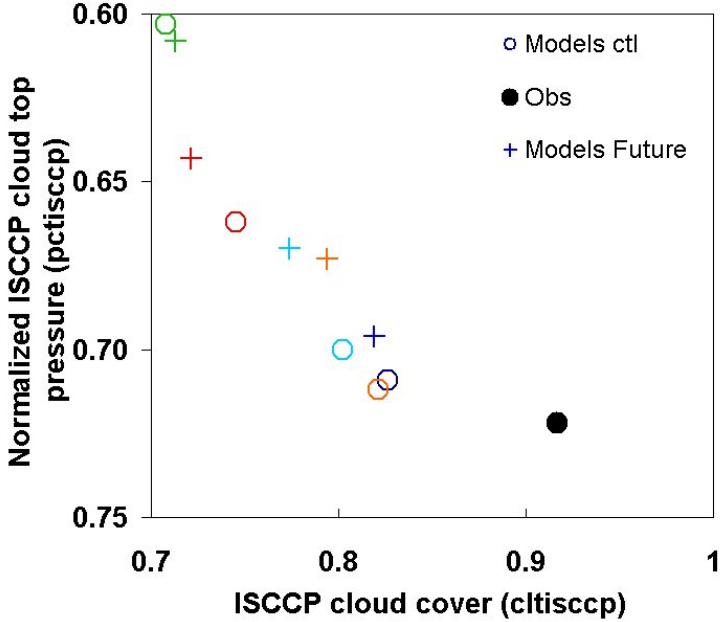


Cloud cover is so different in different models, the relative difference remains similar in warming climate.

If cloud cover is larger, the amount of rained out CCN is larger.

- LWP and Precipitation increases in all models.





models	change in pr[mm/day]	**ratio of large-scale pr in the pr change**
MRICGCM3	0.52	**0.93**
HadGEM2	0.25	**0.65**
MIROC5	0.50	**0.55**
CNRMCM5	0.41	**0.36**

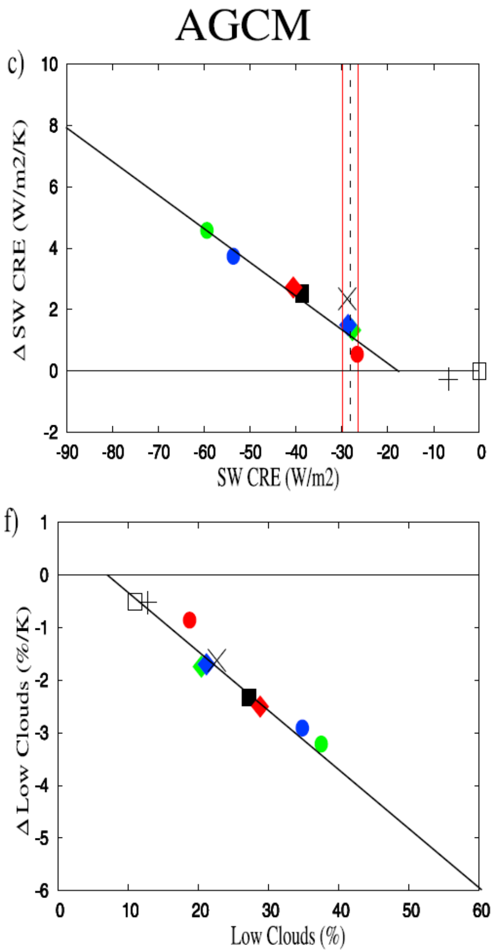
Conclusions

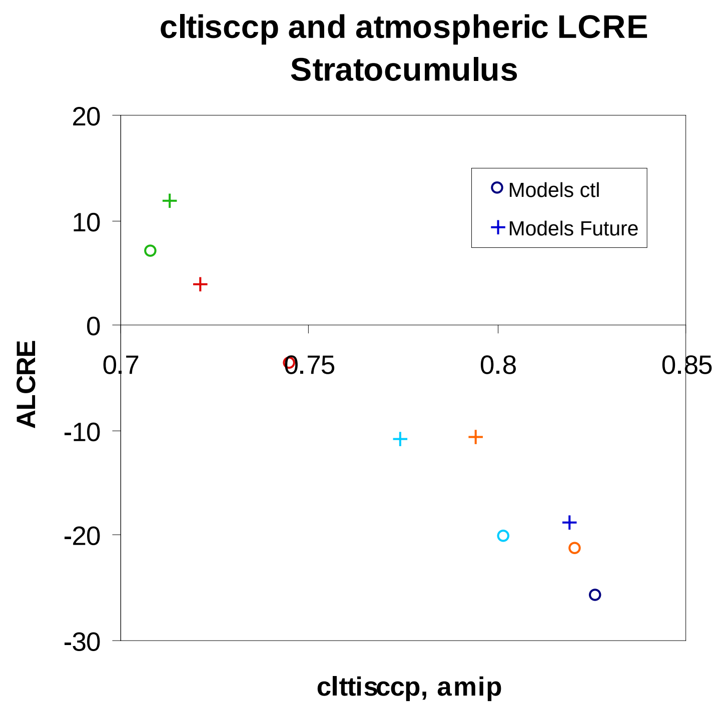
- A strong correlation found in stratocumulus of its in-regime CREs between the magnitudes of the change in different models and their control climate performance were investigated.
- Inter-model difference in in-regime SW CRE in the control climate is mainly correlated to inter-model difference in cloud cover, but that in in-regime SW CRE change in warming climate is mainly correlated to inter-model difference in in-cloud albedo.
- A hypothesis is proposed that inter-model difference in cloud cover makes difference in cloud albedo response through raining out of CCN.
- The correlation found can be used as an emergent constraint of stratocumulus regime, but should be with evaluation of cloud properties (cloud cover, cloud albedo, cloud top of the regime)
    - Compensation error (too small, too bright) matters for inter-model spread in cloud feedback
- Inclusion of better diagnostics in the future CFMIP would be good for further investigation.

What controls cloud cover?

Brient and Bony (2012)

High correlation between low cloud fraction in the control climate and the reduction in higher





In-cloud ACRE and Cloud cover are
highly correlated both in the control and future climate.
but the change does not correlate to in-regime SCRE response.

To have smaller in-cloud albedo with larger in cloud LWP in warming climate, cloud effective radius should increase.

$$c \cdot \tau \approx \frac{3}{2}\frac{W}{r_e}$$

Stephens (1978)

c :cloud cover

τ :optical thickness

W :liquid water path

r_e :cloud effective radius

Cloud water increases in all models.

According to r_e estimate based on this formulation, r_e increases in all models.

Using this equation, we can estimate r_e, and analyze its contribution to cloud albedo decrease.

$$\Delta(c \cdot \tau) = \frac{3}{2}\left\{\frac{1}{r_e}\Delta W \cdot + W \cdot \Delta\left(\frac{1}{r_e}\right) + \Delta W \cdot \Delta\left(\frac{1}{r_e}\right)\right\}$$

Correlation to $\Delta(c \cdot \tau)$ -0.76 0.90 0.86