Assessment of the Seasonal Variation of Cloud Regimes in CMIP5 AMIP experiments

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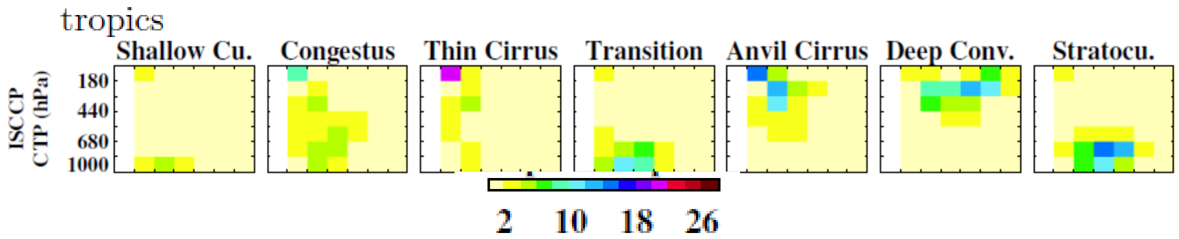
Introduction: Cloud regime analysis



Composite cloud data into different cloud regimes and analyzes them.

- Much of the variance in the climate change cloud response across GCMs is due to differences in the present day simulation of cloud regimes. (Williams and Tselioudis, 2007)
- It is important to assess models' performance on representing cloud regimes.
- Assessment of the cloud regimes in a mean climate (Williams and Webb, 2009)
- Assessment of the climate regimes in the natural variation.

In this study, we analyze seasonal variation of cloud regimes.

Cloud regime analysis : Data and Method

Basically same as Williams and Webb (2009).

- Data and Period:
  - ISCCP D1 total cloud fraction, Cloud albedo, Cloud top pressure
  - Mar1985-Feb1990: ISCCP FD daily radiative flux
- Method
  - Project data of each day onto the reference cluster, and categorize it into closest cloud regimes
  - Cloud regimes constructed by Williams and Webb (2009) are used as reference.
  - Construct climatological mean and climatological monthly mean of RFO and cloud radiative properties for all cloud regimes.
- Area

  based on Williams and Webb (2009)

  - Tropics[20S,20N]
  - Snow/Ice-free extra-tropics

  X snow/Ice covered region

Summary of cloud regimes in mean climate

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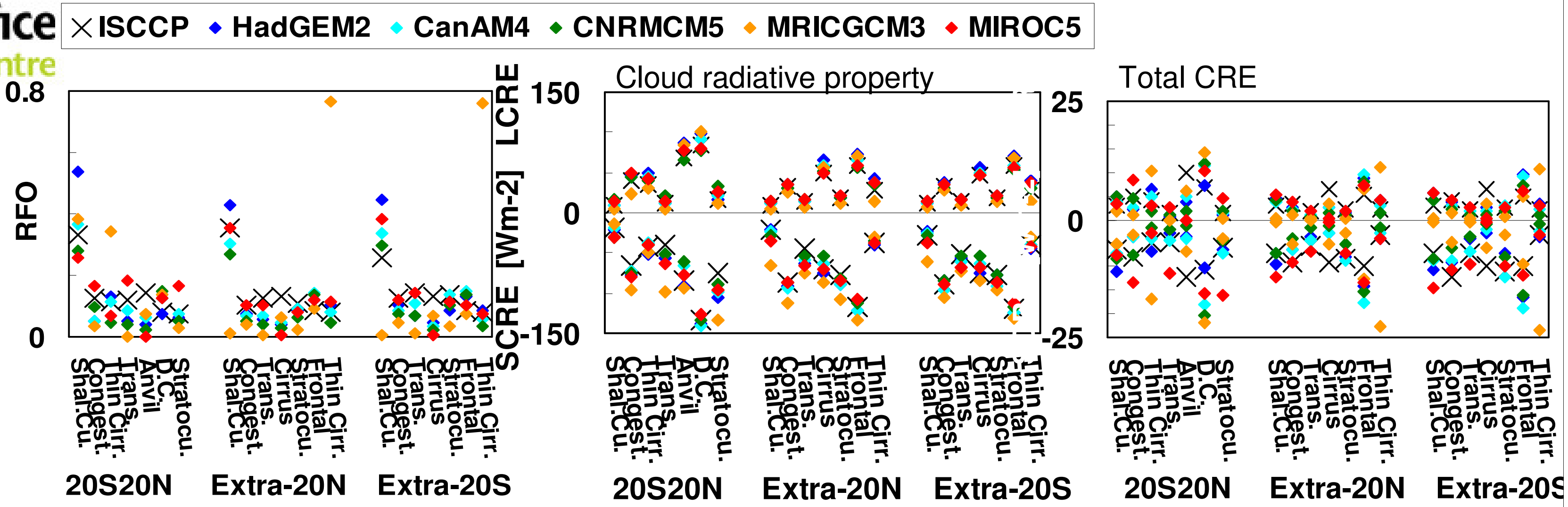


In many regimes, models underestimate RFO and overestimate the radiative property.
Strqtocu overestimate radiative property

Regimes which models' CRE have bias

Region	SW, LW	Net
20S20N	Anvil(u), Deepconv.(o)	Anvil(w)
Extra20N	Cirrs(u),Frontal(o)	Congest(w), Cirrus(w), Frontal(c)
Extra20S	Cirrs(u),Frontal(o)	Congest(w), Cirrus(w)

Regimes of the largest model spread

Region	SW, LW	Net
20S20N	Deepconv.	Transition
Extra20N	Shallowcu	Shallowcu
Extra20S	Shallowcu	Shallowcu

Cloud regime error metric in the present-day (CREMpd) William and Webb (2009)

Models	HadGEM	CNRM-CM5	CanAM4	MRI-CGCM3	MIROC5
CREMpd	0.86	1.53	1.10	2.67	0.92
CREMpd(CMIP3)	1.10		1.25		1.20 (MIROC3)

$$\mathrm{CREMpd} = \sqrt{\frac{\sum_{r=1}^{\mathrm{nregimes}} \mathrm{CREMpd}_r^2}{\mathrm{nregimes}}}$$

$$\mathrm{CREMpd}_r = \mathrm{aw}\sqrt{(\mathrm{NCRF}'_r \mathrm{RFO}_{\mathrm{obsr}})^2 + (\mathrm{RFO}'_r \mathrm{NCRF}_{\mathrm{obsr}})^2}$$

NCRF': NCRF error of the cluster, RFO': RFO error of the cluster, aw: area weighting term

Cloud regime analysis : Seasonal variation

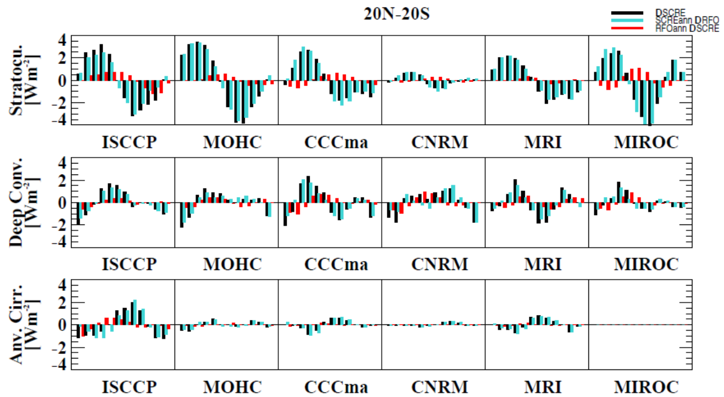
Our questions

- Which cloud regime cluster have the largest amplitude of seasonal variation of CREs?
- Which cloud regime cluster have large spread in the RMS error of seasonal variation of CREs among the models?
- Which cloud regime cluster have systematic RMS error of seasonal variation of CREs among the models?

  Is the important cloud regime in the seasonal variation same as the one in the mean climate or different?

- Which of the variation in RFO or the cloud radiative property is responsible for the variation of CREs?
- Which of the error in amplitude or the error in time variation pattern is responsible for them?

- How big are the variation of cloud radiative effect by the RFO variation and cloud radiative property variation?



- It is found that the variation of cloud radiative effect is dominated by RFO variation.
- In the following analysis, we just regard the variation of CREs (i.e. represent RFO variation; not breaking down into the variation of RFO and cloud radiative property).
  - In the extra tropics, the solar insolation variation contributes to the SCRE's "radiative property variation". Instead, we use annually normalized shortwave cloud radiative effect (**N**SCRE), instead of SCRE.

Seasonal variation of CREs

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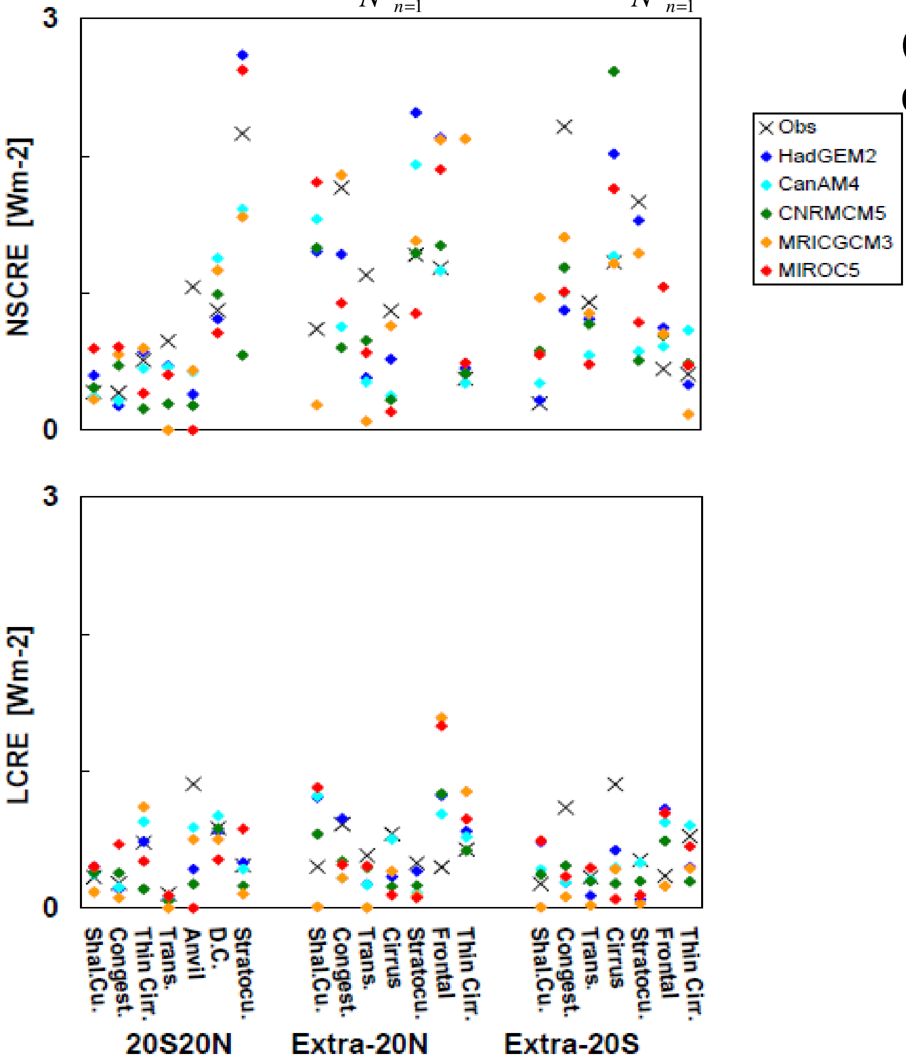
$N = 12$

$m_n = nscre_r(model = m, month = n)$

$$\sigma_m{}^2 = \frac{1}{N}\sum_{n=1}^{N}\left(o_n - \bar{o}\right)^2 \quad \sigma_m{}^2 = \frac{1}{N}\sum_{n=1}^{N}\left(m_n - \bar{m}\right)^2$$

$$E'^2 = \frac{1}{N}\sum_{n=1}^{N}\left\{\left(m_n - \bar{m}\right) - \left(o_n - \bar{o}\right)\right\}^2$$



Cloud regime with the largest amplitude of CRE seasonal variation

Region	Net
20S20N	Stratocu
Extra20N	Congest.
Extra20S	Congest.

Cloud regime largely biased in the model

Region	SW	LW
20S20N	Anvil(u)	Anvil(u)
Extra20N	Trans.(u)	Trans.(u)
Extra20S	Congest.(u)	Congest.(u), Cirrus(u)

Cloud regime with the largest spread in the RMS error from the observation

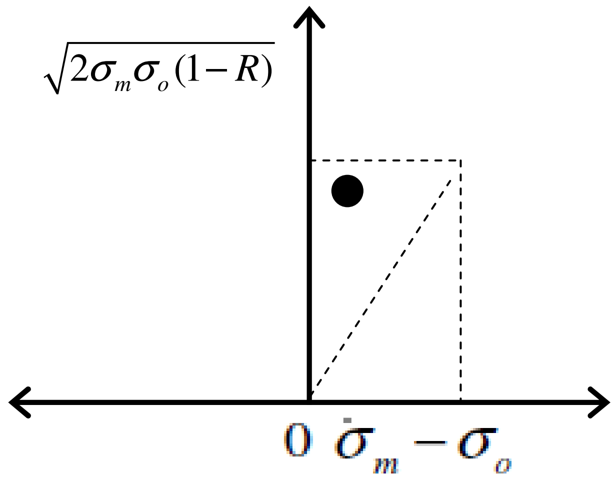
Region	Net
20S20N	Stratocu
Extra20N	Stratocu
Extra20S	Congestus

Error in the amplitude and error in the time variation pattern

$$E'^2 = \sigma_m^{\ 2} + \sigma_o^{\ 2} - 2\sigma_m\sigma_o R$$

It can also be rewritten as follows

$$E'^2 = (\sigma_m - \sigma_o)^2 + 2\sigma_m\sigma_o(1-R)$$



Break down of the contributions of the error in the amplitude and error in the time variation pattern to the total RMS error.

Thought experiments:
with perfect correlation in the time variation,

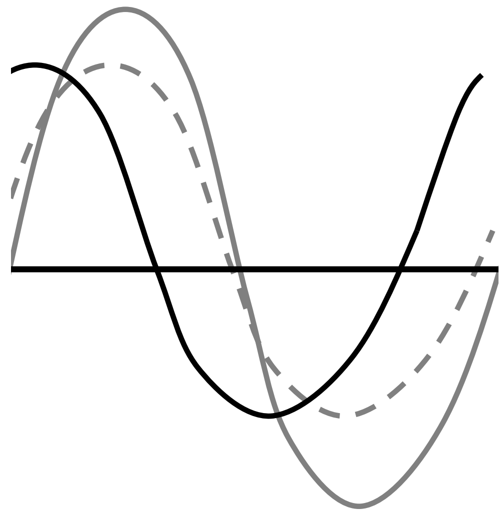
$$E'^2 = (\sigma_m - \sigma_o)^2$$

With perfect agreement in the standard deviation

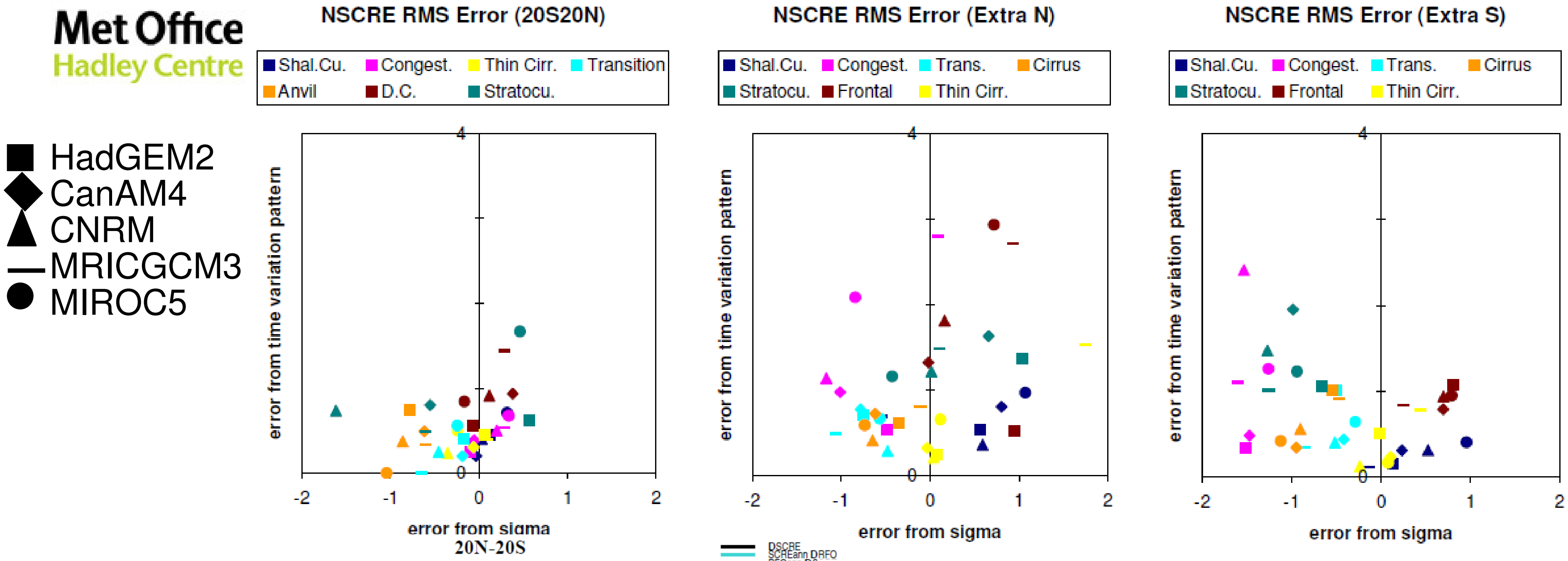
$$E'^2 = 2\sigma_r^{\ 2}(1-R)$$

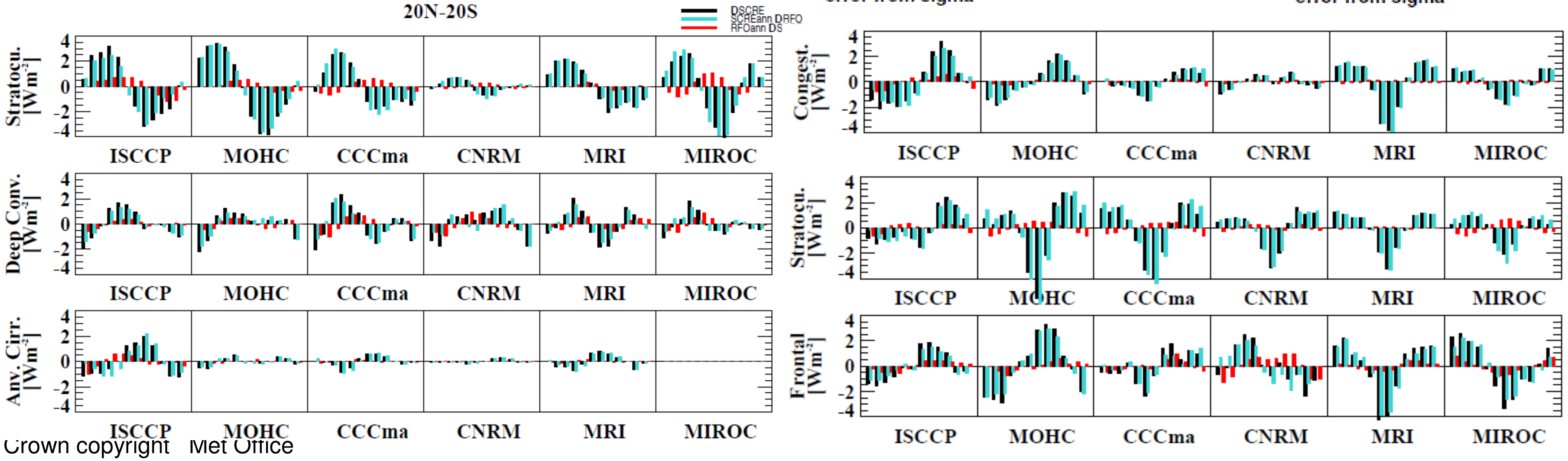
$$2\sigma_m\sigma_o(1-R) = \frac{\sigma_m}{\sigma_o}2\sigma_o^{\ 2}(1-R)$$

$$2\sigma_o^{\ 2}(1-R) = \dots = \frac{1}{N}\sum_{n=1}^{N}\left\{\frac{\sigma_o}{\sigma_m}\left(m_n - \overline{m}\right) - \left(o_n - \overline{o}\right)\right\}^2$$

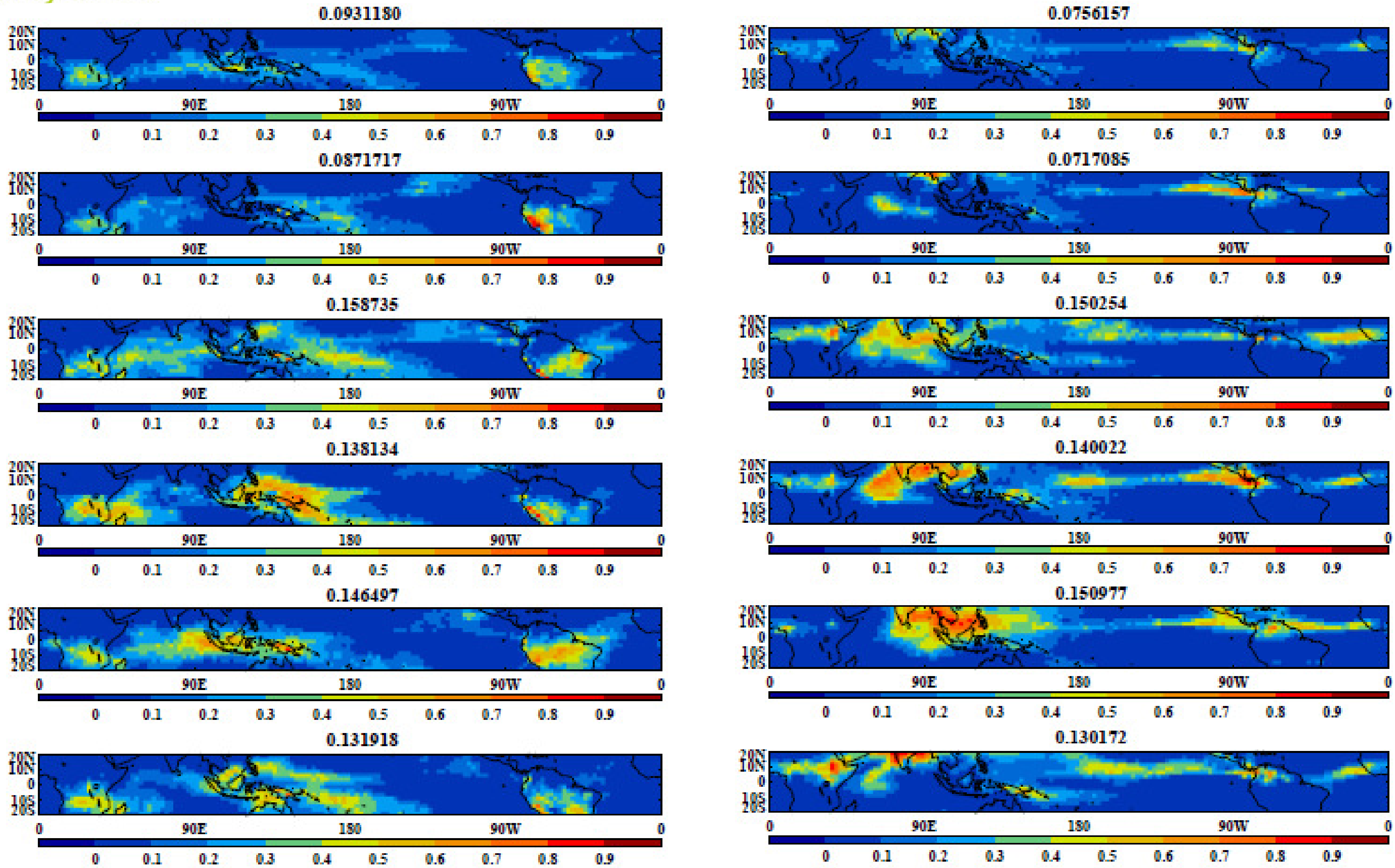


Amplitude error &time variation pattern error

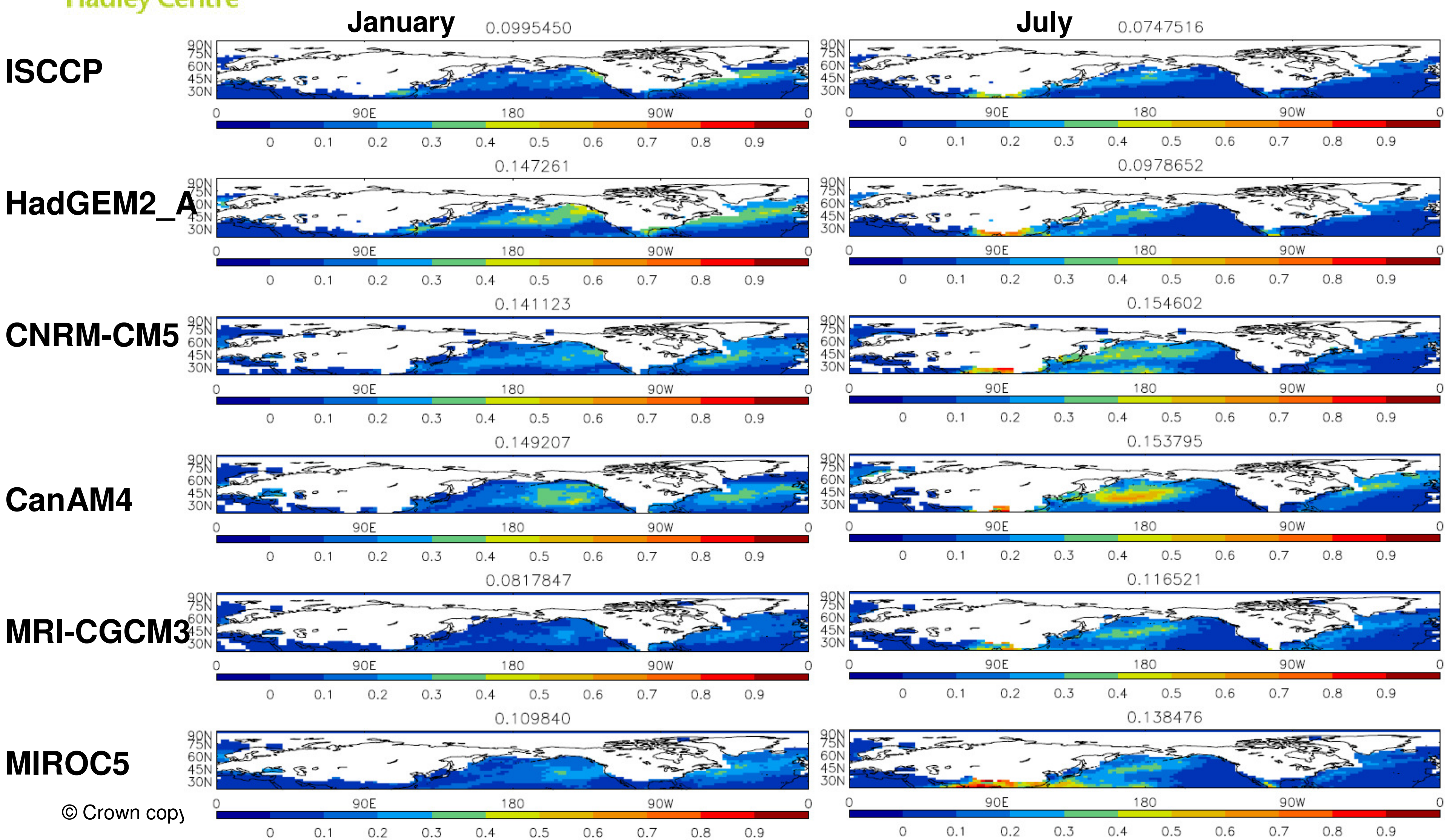




Example: Deep convective cluster



Example: Frontal cluster



Summary

- Seasonal variation of cloud radiative effects of each cloud regimes are analyzed and those in CMIP5 models are evaluated.
- Tropics cloud regimes have better agreement of seasonal variation than the extra tropics
- In the tropics, Stratocu has the largest amplitude of seasonal variation of CREs in the tropics, and the largest spread in RMS error among models, which may come from the large mean cloud radiative effect bias.
- In the extra tropics, Congestus has the largest mean cloud radiative effect and also has the largest RMS error among models.
- Systematic error in the amplitude of CRE variation is found (ex. Anvil, transition, congestus)

Summary

- Diagnostics have been devised, which facilitate us to see the contributions of the error in the amplitude and error in the time variation pattern to the total RMS error.
- CMIP5 models' error in cloud radiative effects in the amplitude and that in the time variation pattern are equally responsible to the spread of their RMS errors in the seasonal variation.
  - In the extra-tropics, the models which have larger RMS error in the Extra-Tropics tend to have larger time variation pattern error.
- It is confirmed that these diagnostics pick up each models' characteristics of error pretty well.
- provide us to obtain clearer view of the model's current performance of seasonal variation of clouds.

Future Plan

- Application to interannual variation
- Application to CMIP5 models and see relevance of each cloud regime’s response in global warming and natural climate variation.
- Introduction of the metrics to GCM metrics community.