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Robust Signals of High and Low Cloud Feedbacks from AIRS, MODIS, and CERES Observations

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Outline

- Empirical Cloud Radiative Kernel method
- The temporal, spatial, spectral features of short-term cloud feedback from AIRS, MODIS, CERES
- Application to study climate model cloud feedback

Take-home message:
Spectral, temporal, and spatial structures of short-term cloud feedback by cloud type from observations reveal robust signals from current satellite observation data record to constrain the climate model cloud feedback.

Cloud Feedback Definition(s)

The change of global mean cloud-induced radiative anomalies (ΔR_G) at TOA in response to 1K change in global mean surface temperature (ΔT_{GS}).

$$\lambda_{GG}(c) = \frac{\Delta R_G(c)}{\Delta T_{GS}} = \frac{\overline{\Delta R(c,\phi)}}{\Delta T_{GS}}$$

- Long-term climate change, λ_{GG} is a measure of cloud contribution to the stability of global climate with respect to forcing.
- On shorter time scale or transient warming: varies with time

Consider energy balance at local scale (e.g. Armour 2013, Rose et al. 2014)

$$\lambda_{LL}(c,\phi) = \frac{\Delta R(c,\phi)}{\Delta T_S(\phi)},$$

$$\lambda_{GG}(c) = \overline{\lambda_{LL}(c,\phi)\frac{\Delta T_S(\phi)}{\Delta T_{GS}}}$$

- λ_{LL} (nearly) time-invariant?
- If so, temporal variability is mainly coming from the response of local surface temperature to the global mean surface temperature change (e.g. Armour 2013).

Still the local feedback concept, as in Zhou et al. (2017):

$$\lambda_{GL}(c,\phi) = \frac{\Delta R_G(c)}{\Delta T_S(\phi)} = \overline{\Delta R(c,\phi)} \Big/ \Delta T_s(\phi)$$

- Local feedback shows strong temporal variability.
- the scaling relationship cannot reconstruct the global cloud feedback.

$$\lambda_{GG}(c) = 1 \Big/ \overline{\left(1/\lambda_{GL}(c,\phi)\right)}$$

Yue et al. 2018

Importance of Observation Constraints
Observations: short record, uncertainty from various sources

Cloud Radiative Kernel (CRK) Method to Calculate Cloud Feedback by Cloud Type

$$CRF = F_{clr} - F_{all\_sky} = C(F_{clr} - F_{ovc}).$$

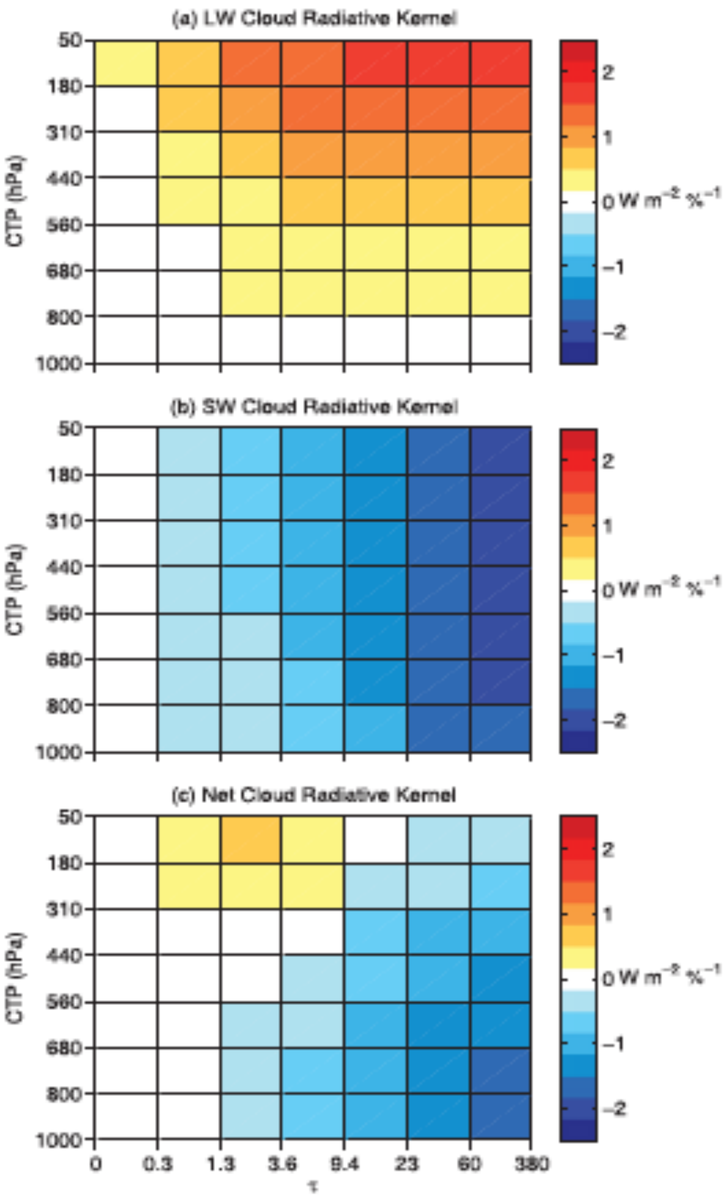
CRF: Cloud Radiative Forcing
C: Cloud fraction
F_{clr}: clear-sky TOA flux F_{ovc}: overcast-sky TOA flux

$$K \equiv \partial CRF / \partial C$$

K: Cloud Radiative Kernel, sensitivity of TOA radiation to cloud.

First proposed by Zelinka et al. (2012) to determine directly the cloud feedback by ISCCP CTP-τ cloud types

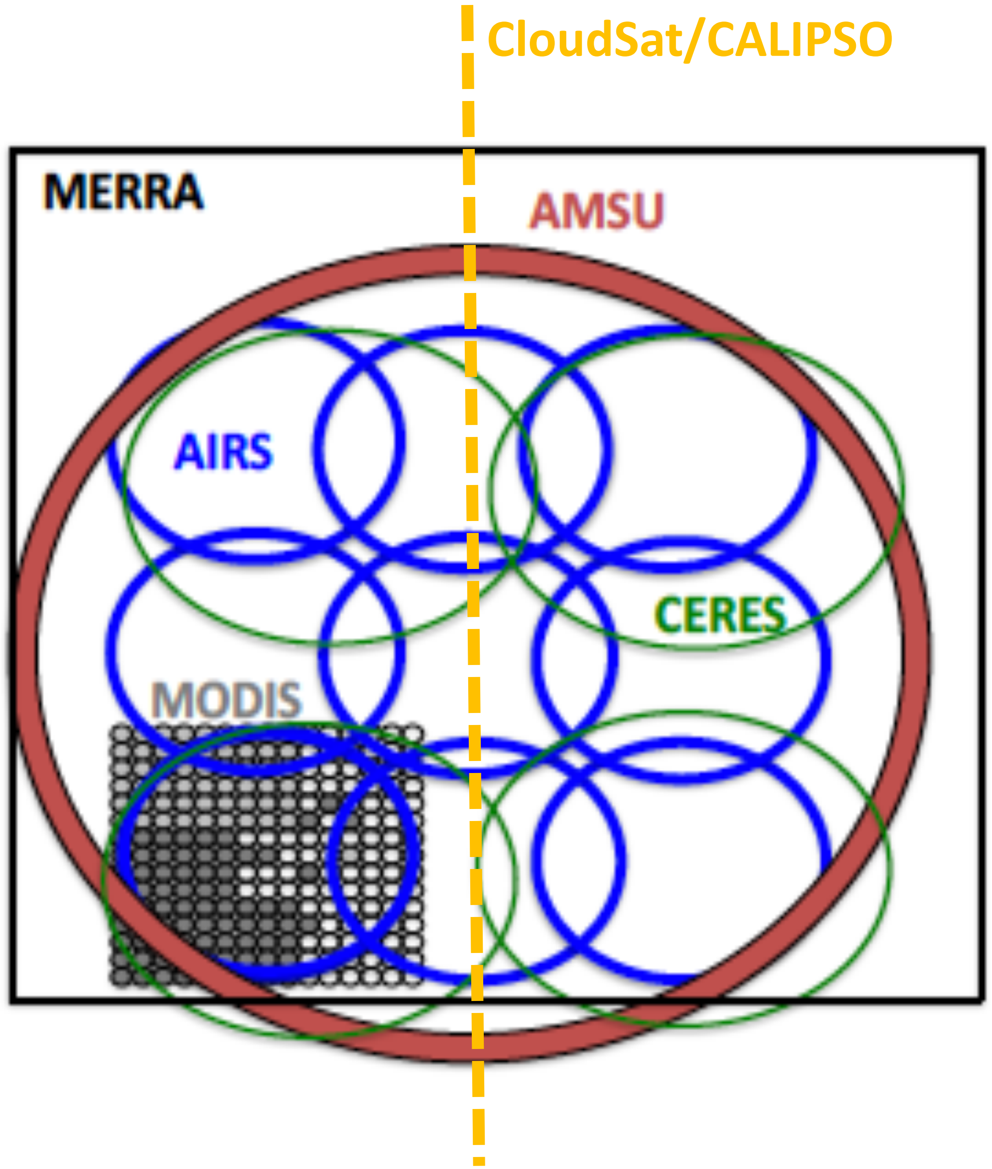
- Cloud type defined as ISCCP CTP-τ histogram
- Fu and Liou model.
- Zonal and monthly mean T and Q profiles from control runs of 6 GCM
- Assuming plane parallel single-layer overcast cloud, with synthetic cloud and surface properties.
- “Clear sky”: cloud-removed.



Apply the traditional kernels directly to satellite observed (retrieved) cloud data record.

1. Clouds in observations are different from those in models.
2. Consistency between kernels and the response term.
3. A-Train measures radiation, cloud, and atmosphere simultaneously.

Pixel-scale Collocated Multi-Satellite Obs. and Reanalysis



- **Cloud:** MODIS (1km and 20km)
- **TOA Radiation:** spectrally resolved and broadband OLR from AIRS (13km), CERES (20km)
- **TOA Clear-Column Radiation:** MERRA (1/2 X 2/3, hourly) , AIRS-Calculated (50km)
- **Atmosphere and Surface:** AIRS/AMSU (50km), MERRA
- **Vertical profiles of cloud and radiative heating:** CloudSat/CALIPSO (1.4 X 1.7km)

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Observation-based Cloud Radiative Kernel

$$CRK = \frac{\partial CRF}{\partial C} = \frac{CRF}{C} = \frac{F_{clr} - F_{all-sky}}{C}$$

CRK ($Wm^{-2}\%^{-1}$) obtained by different data and methods (Yue et al. 2016a and Yue et al .2018b). Spectral LW CRK.

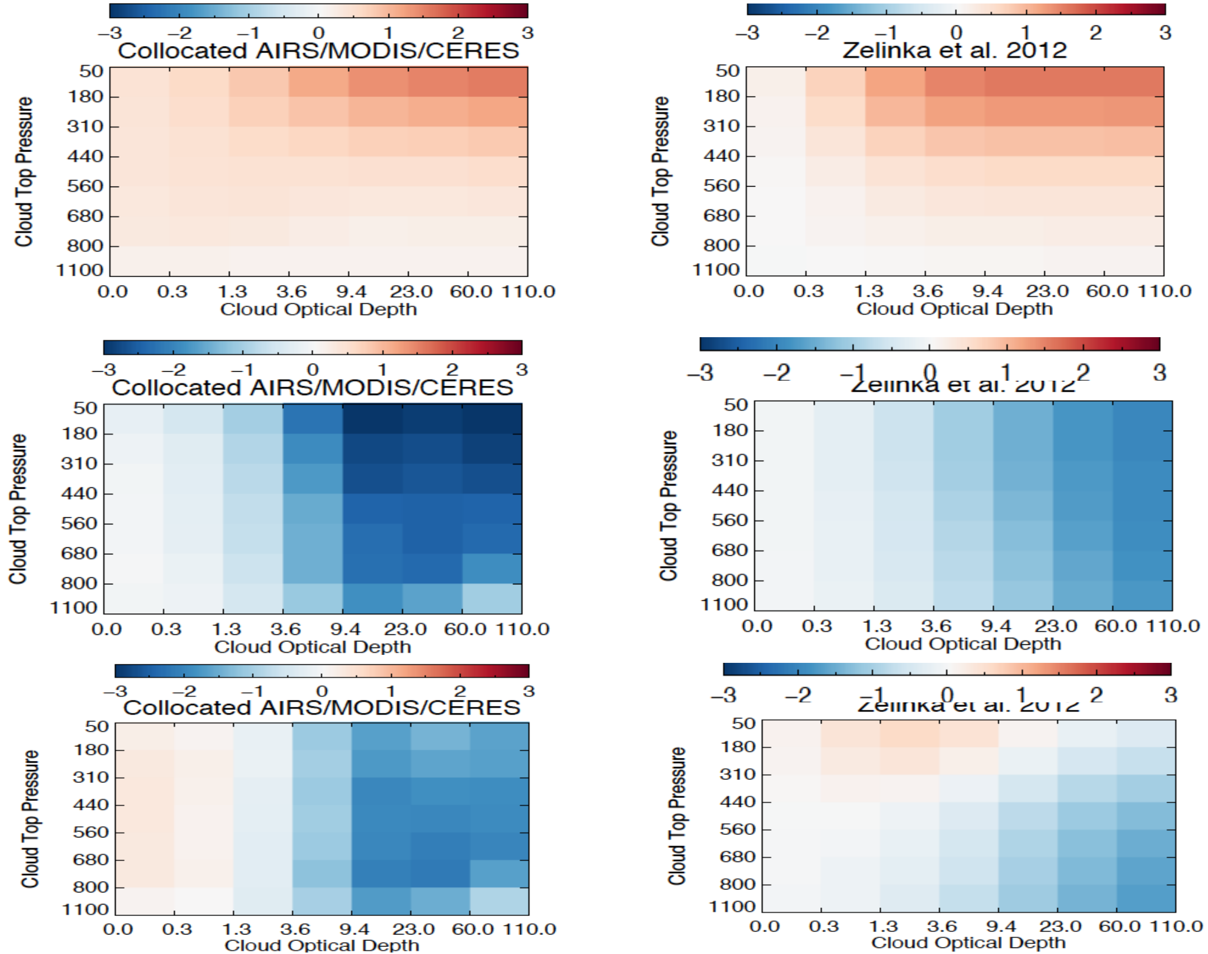
Standard MODIS cloud (MAST-MODIS), CERES flux, AIRS ECF.

RT-based (Zelinka et al. 2012)

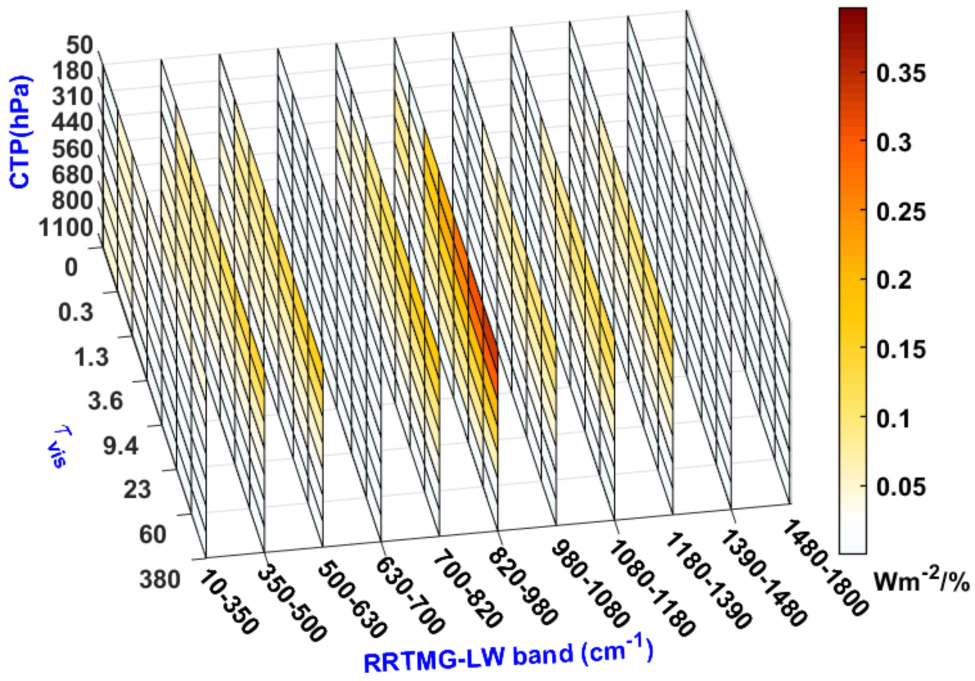
LW

SW

Net



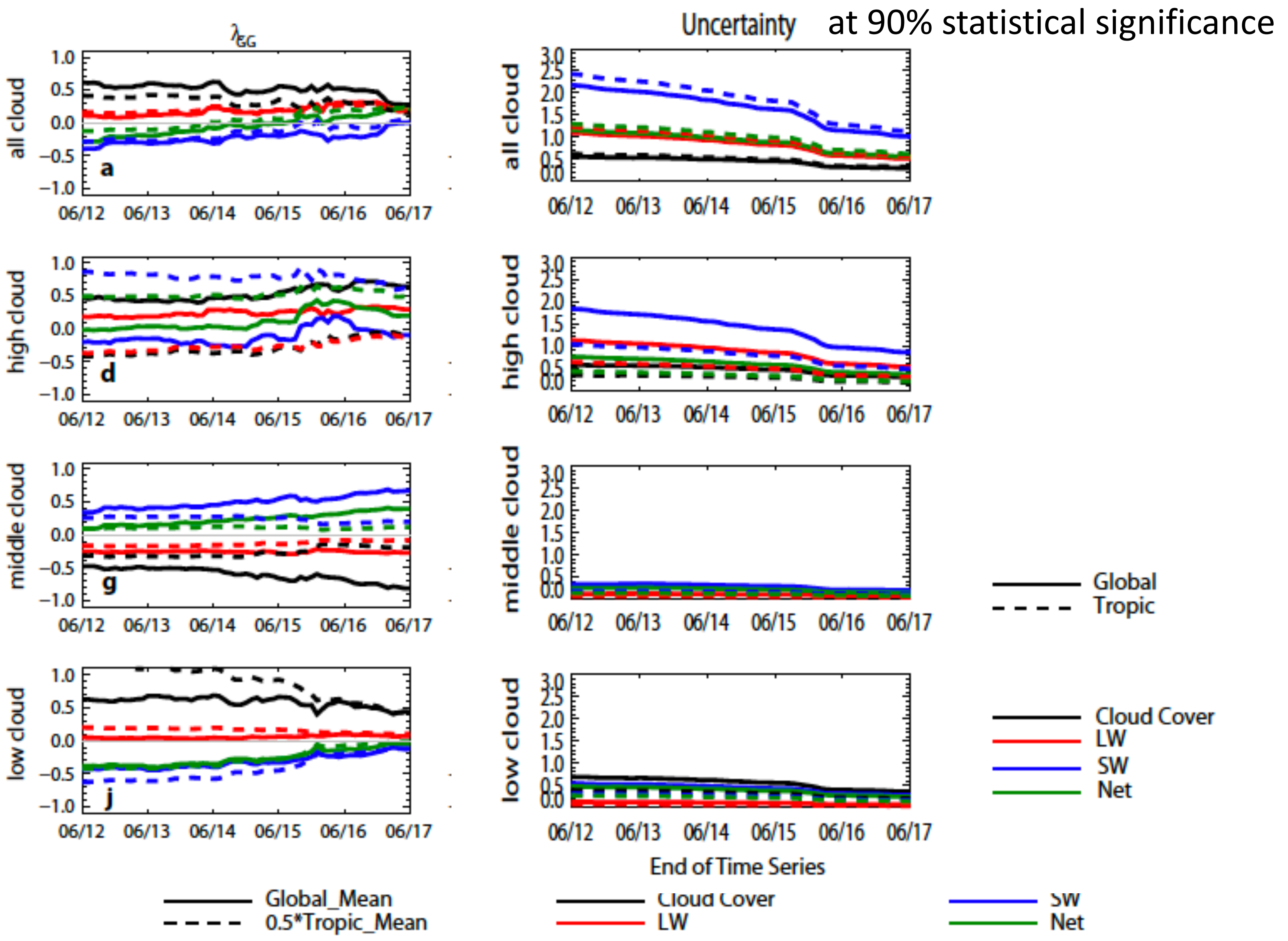
Spectral OLR AIRS+CERES, MODIS cloud



Yue et al. 2016, Huang et al. 2018

Cloud Feedback to Interannual Climate Variability during the A-Train Era: Magnitude

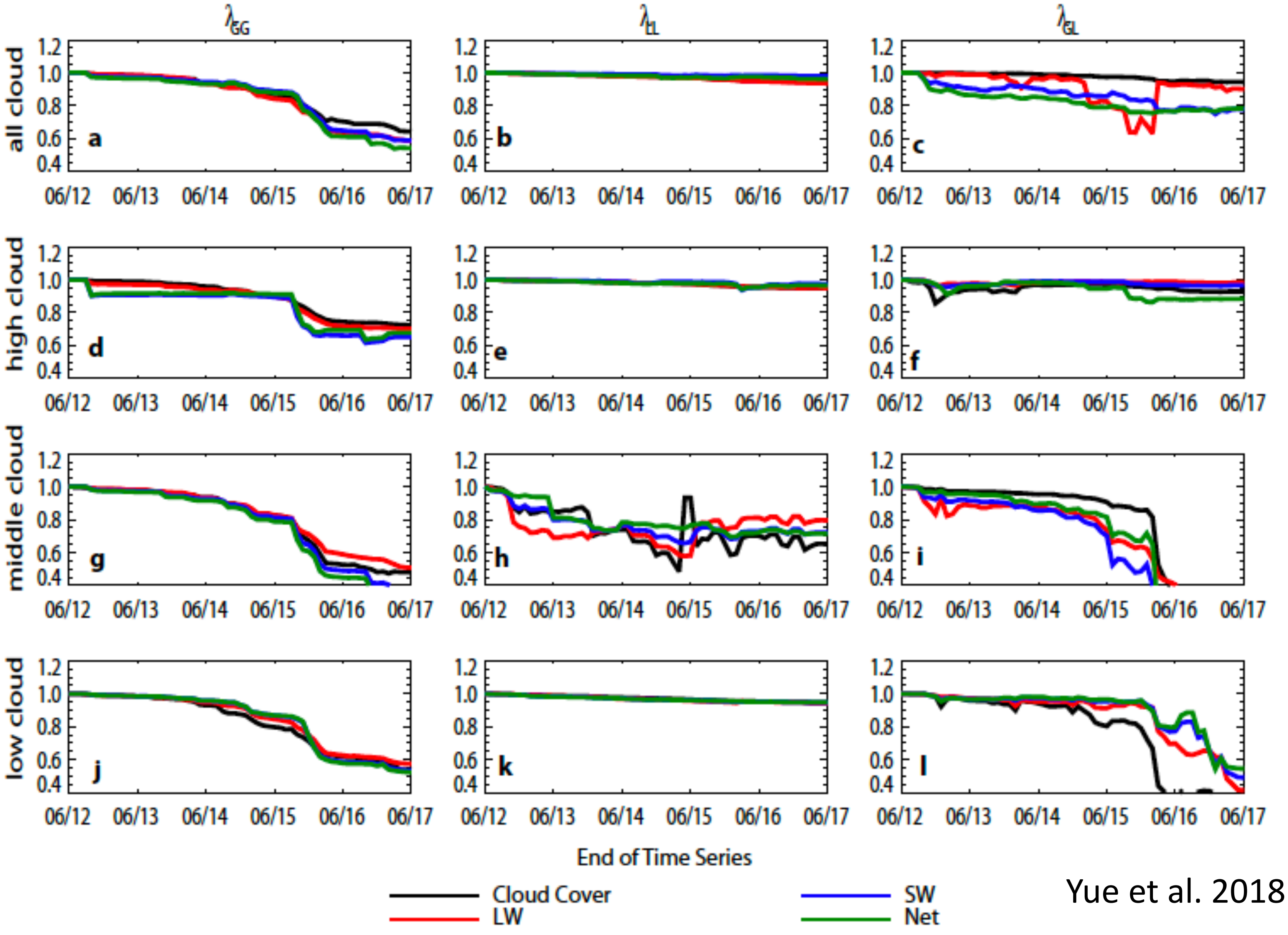
- During A-Train era, the temporal variability in λ_{GG} to interannual climate variability is contributed by both high cloud and low cloud.
- Significant temporal variability in local feedback defined by λ_{GL} −> nonlocal effect included by definition.
- Negative to positive transition in net total λ_{GG} contributed mainly by decreasing negative λ_{GG} for low clouds, and also by increasing positive λ_{GG} for high clouds



Yue et al. 2018

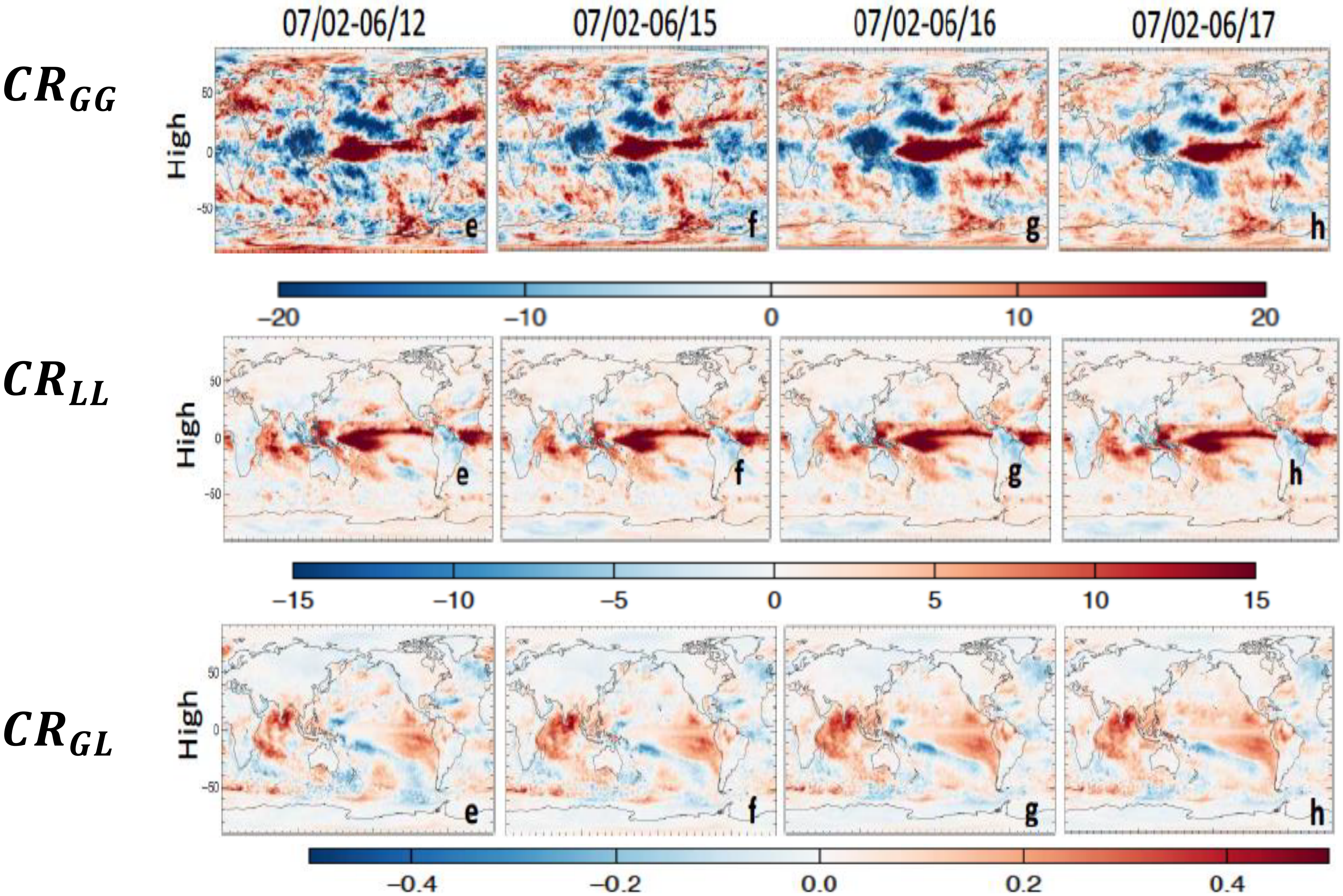
Cloud Feedback to Interannual Climate Variability during the A-Train Era: Pattern

- Nearly time-invariant magnitude and spatial patterns of λ_{LL}.
- These conclusions also hold for different cloud types.

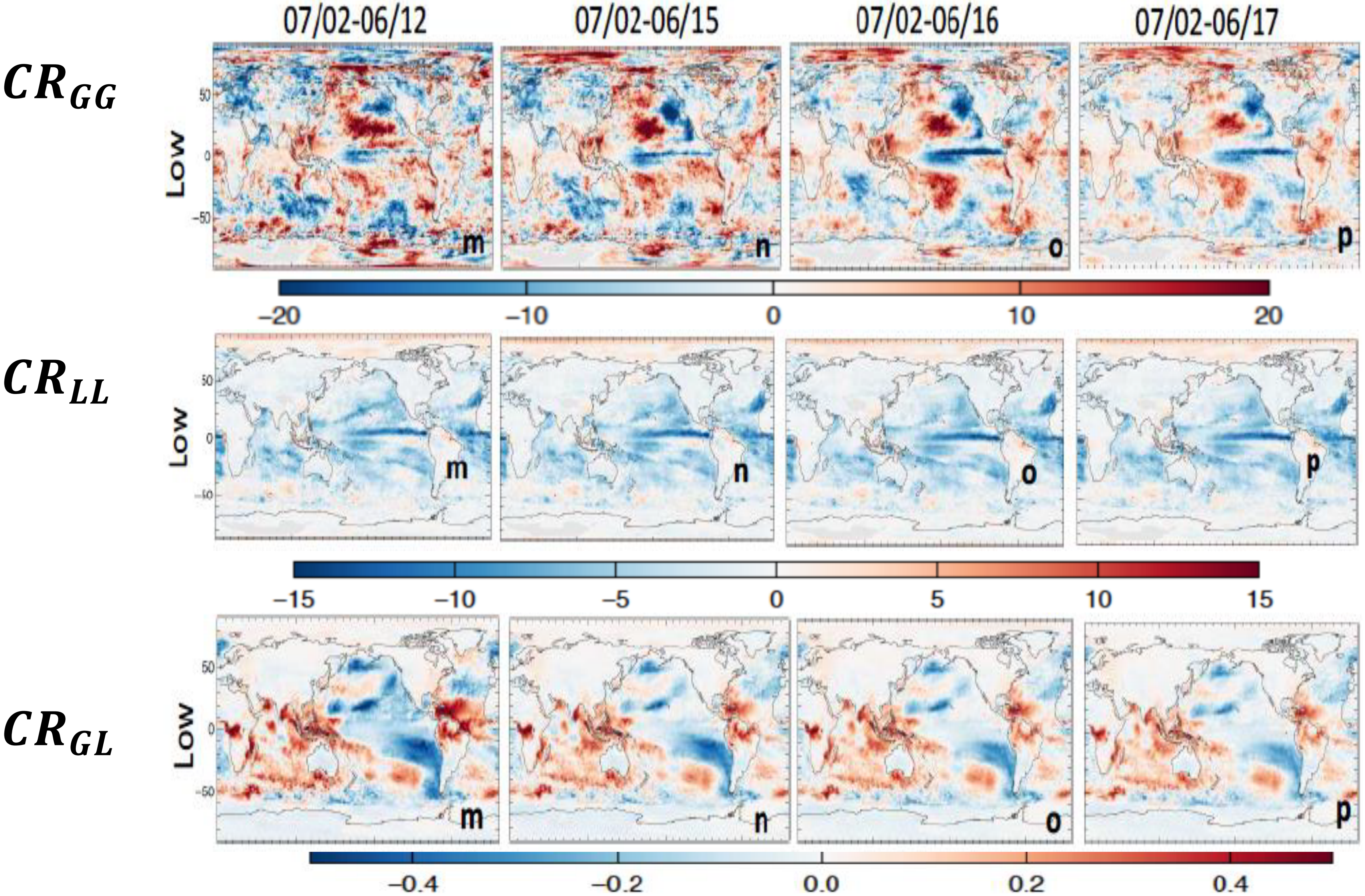


Yue et al. 2018

High Cloud Cover Response (CR, %/K) from A-Train

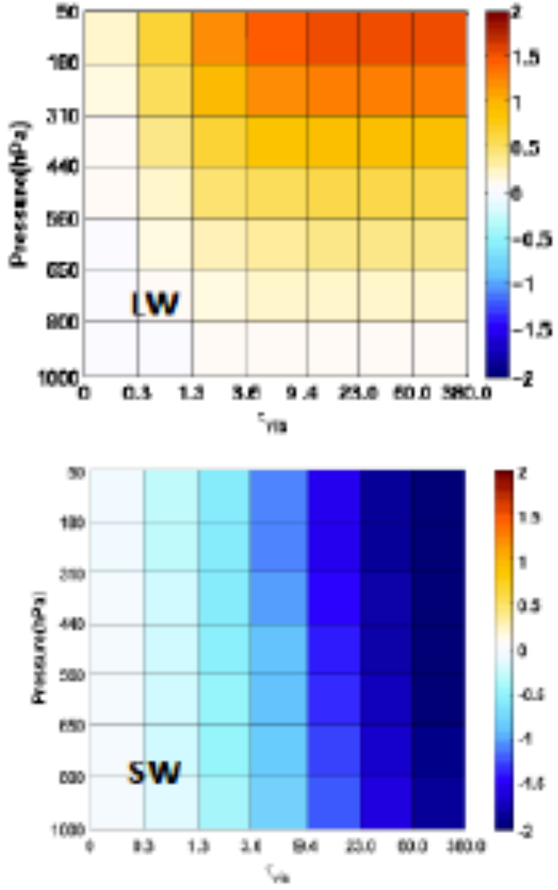


Low Cloud Cover Response (CR, %/K) from A-Train

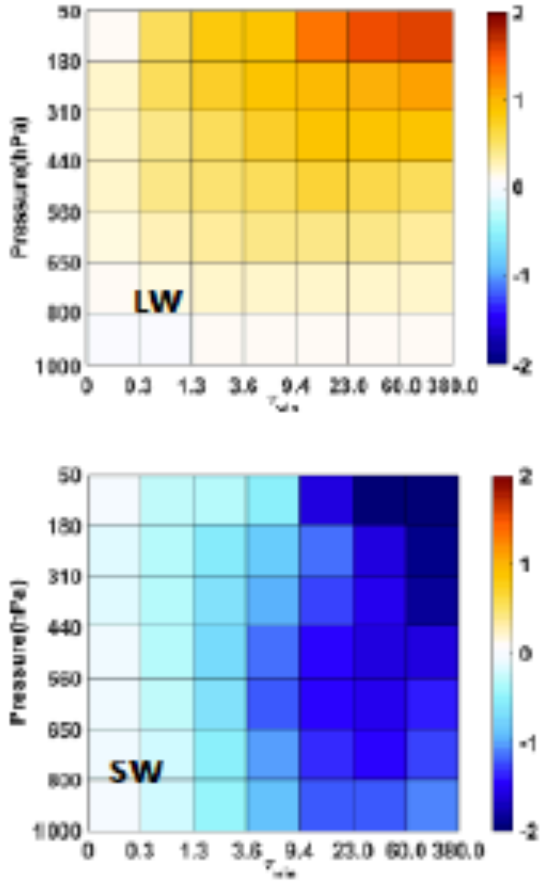


Application to Climate Model Simulations

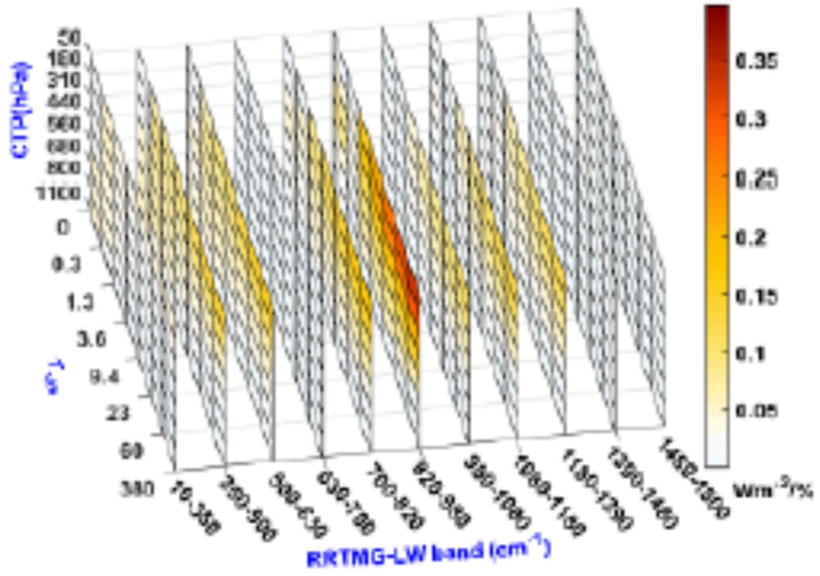
Traditional CRK
(Zelinka et al. 2012)



Empirical CRK for
CAM4



Empirical Spectral LW
CRK for CAM4



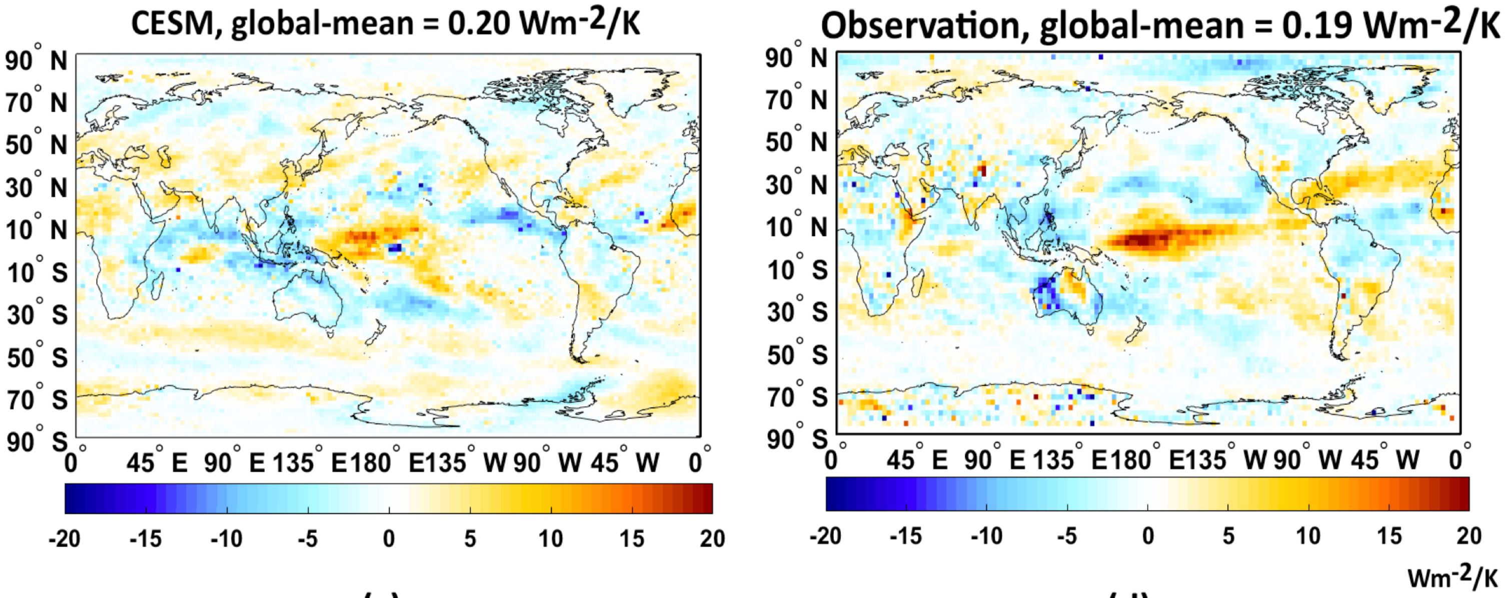
Deriving CRKs from model-specific cloud and TOA radiative flux data
High temporal resolution model output is required

Huang et al. 2018

Constraining Climate Model Short-term Cloud Feedback Using Observations On Temporal, Spatial and Spectral Characteristics

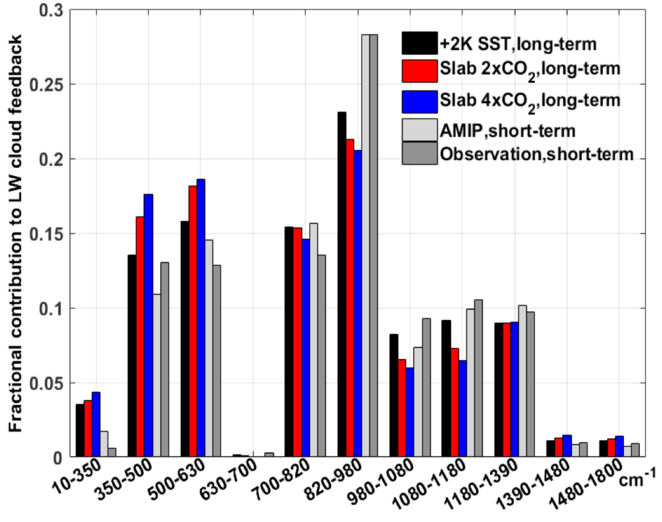
Short-term LW cloud feedback from CAM4 and A-Train (2003-2013)

(a) (b)



Spectral contribution to the LW cloud feedback: window band dominates for short-term cloud feedback and far-IR contribution larger in long-term cloud feedback

(c)



(d)

	Total fractional contribution from 10-630 cm^{-1} (far-IR)	Total fractional contribution from 820-1180 cm^{-1} (window)
+2K SST	0.33	0.40
Slab $2xCO_2$	0.38	0.35
Slab $4xCO_2$	0.40	0.33
AMIP	0.27	0.45
Observation	0.26	0.48

Summary

Spectral, temporal, and spatial structures of short-term cloud feedback by cloud type from observations reveal robust signals from current satellite observation data record to constrain the climate model cloud feedback.

- Robust signals for high and low cloud feedbacks over the tropical and subtropical regions.
- Different approaches to calculate cloud feedback using the conventional linear climate feedback framework reveal different aspect of cloud feedback and processes associated.
- Model-specific empirical CRKs can be derived from high-temporal model output on cloud and TOA radiative flux fields.

Net Total Cloud Feedback ($Wm^{-2}K^{-1}$) from A-Train