Jet Propulsion Laboratory
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Observation-based Longwave Cloud Radiative Kernels Derived from the A-train

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AIRS and MEaSUREs

Outline:

- What is radiative kernel? What is cloud radiative kernel?
- Methodology and Data
- Observation-based IR cloud kernels: With and without cloudy radiative transfer calculation
- Uncertainty
- Summary and future work

Radiative Kernel

$$\lambda_X = -\frac{\delta_X \overline{R}}{\delta X}\frac{\delta X}{\delta T_s}$$

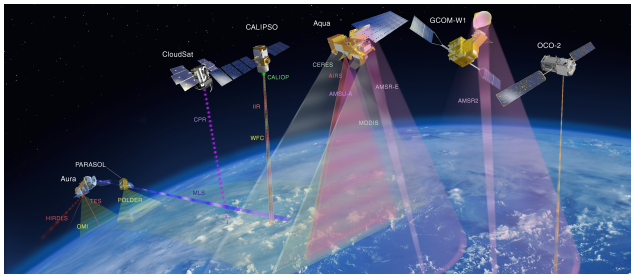
Climate feedback parameter for variable X

Radiative kernel of X: Base climate state and radiative transfer

Climate response term: change of X between two climate states directly related to a specific feedback

X: water vapor, temperature, surface albedo.
If X=Cloud, nonlinearities in the radiative transfer of cloud due to the cloud vertical distributions.

1. Can we have a cloud kernel? Radiatively-relevant cloud top as seen by satellite topdown
2. Cloud types
3. Since A-Train observes everything, can we derive kernels independent of model simulations and radiative transfer models?



Cloud Radiative Forcing (CRF) and Cloud Radiative Kernel (CRK)

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

CRF: Cloud Radiative Forcing
C: Cloud fraction
F_{clr}: clear-sky TOA flux F_{ovc}: overcast-sky TOA flux (when C=100%)

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

K: Cloud Radiative Kernel to directly access the cloud radiative feedback by cloud type using the concept of radiative kernel

1. **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.
2. **"Observational-based" cloud radiative kernels: Zhou et al. (2013)**
   - Monthly mean fields from ERA-Interim from 2000 to 2010).

Atmospheric Cloud Radiative Forcing (ACRF)

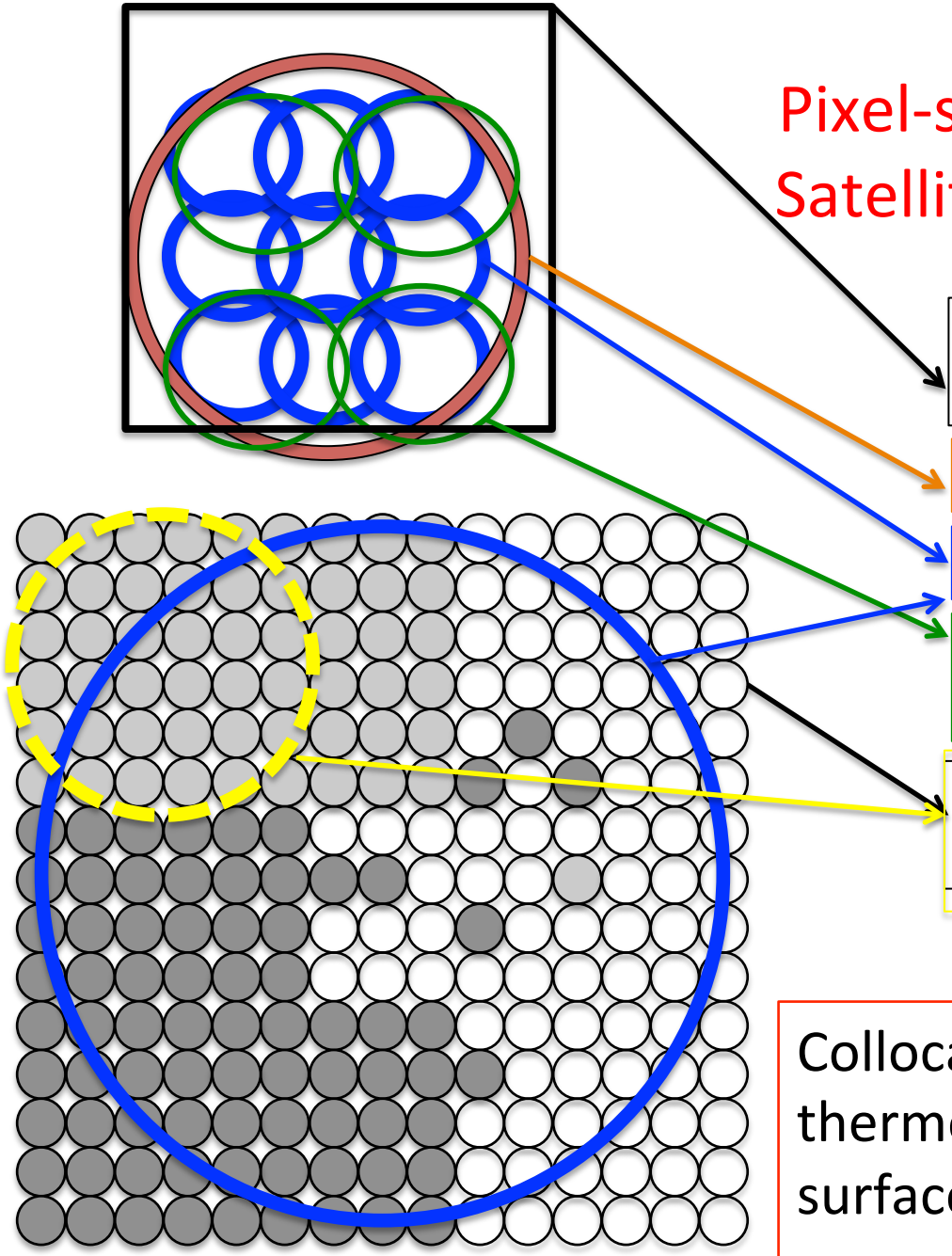
One difference between model-calculated and observation-derived CRF is that the latter often includes the contribution from the radiative effect of differences on atmospheric temperature and moisture structure between clear and cloudy conditions.

$$\Delta CRF = CRF[observed\_clear] - CRF[cloud\_removed]$$
$$= C(F_{clr}[observed\_clear] - F_{clr}[cloud\_removed])$$

- No cloudy radiative transfer calculation is needed.
- Can be done with small subsets of atmospheric states data.

Should it be included in the cloud feedback?

Data:
Pixel-scale Collocated Multi-Satellite Obs. and Reanalysis



MERRA reanalysis (1.25X1.25, 3-hrly)
MERRA reanalysis (1/2 X 2/3, hourly)

AIRS/AMSU L2 Retrieval (45 km)

AIRS cloud and radiances (13 km)

CERES TOA fluxes (20km) and CERES-MODIS cloud properties

MODIS cloud mask (1km)
MODIS Level 2 cloud retrieval (1 and 5km)

CloudSat

Collocated radiation, atmospheric thermodynamic, dynamics, and surface condition and their correspondent cloud condition data

We Derive Three Sets of Kernels

Two Observation-based CRKs

From two sets of obs.

1. Collocated AIRS/CERES/MODIS
2. CERES Level 2 footprint data product, the Single Satellite Footprint (SSF) TOA/Surface Fluxes and Clouds Edition 3A

One Model-based CRK

- Following Zekinka et al. (2012) and Zhou et al. (2013)
- MODIS-Aqua L2 cloud observation and AIRS Level 2 data collocated MERRA reanalysis (CloudSat)
- MERRA surface and atmosphere classified by MODIS CTP-τ cloud histogram
- Clear-sky:
  1. AIRS effective cloud fraction is less than 0.01
  2. Cloud-removed atmospheric column

Quantify Uncertainties: contribution from ACRF, different MODIS cloud retrieval algorithms, different definitions of clear sky, assumption of single layer cloud

Global Distribution of The Occurrence Frequency For Clear Sky and Different Cloud Types

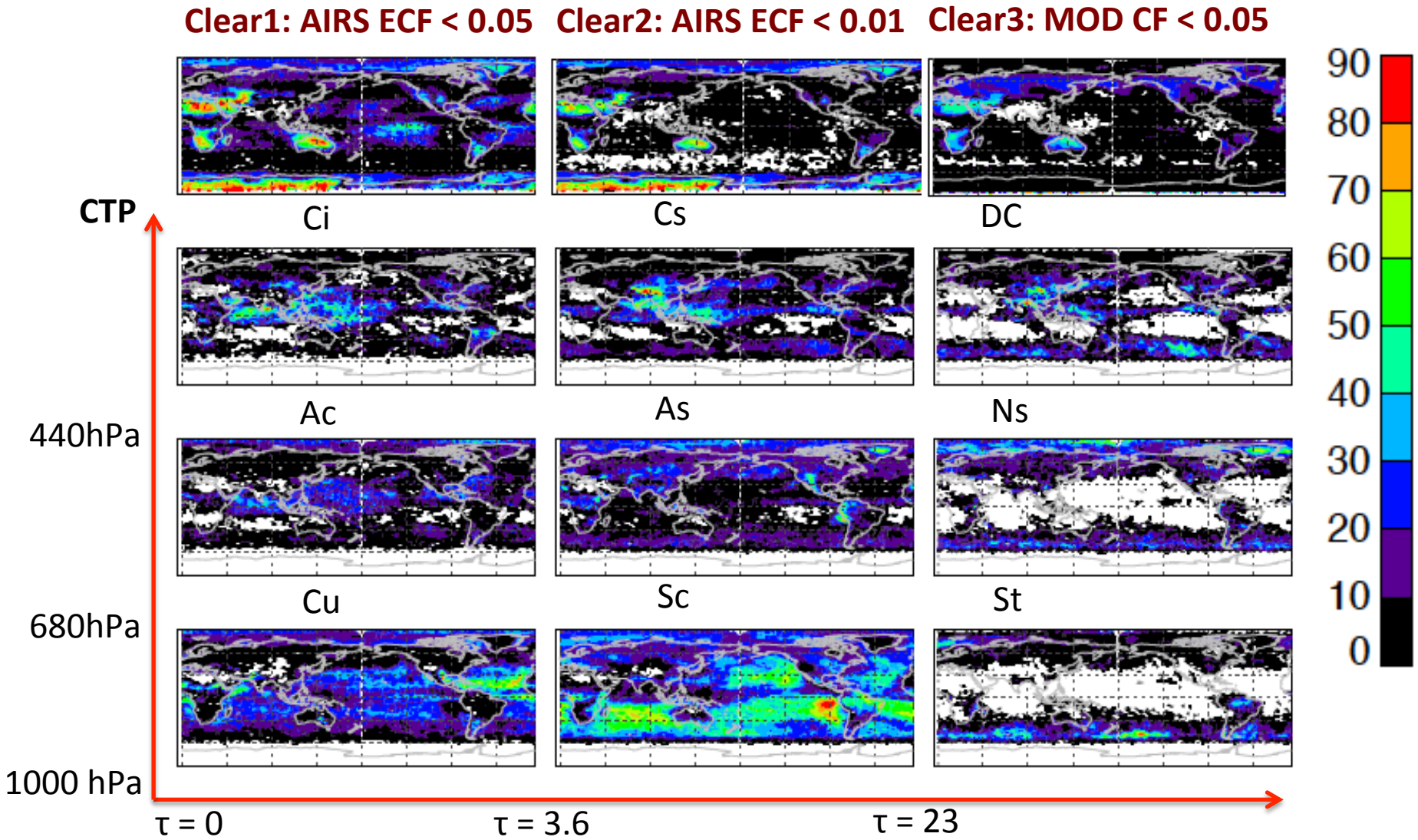
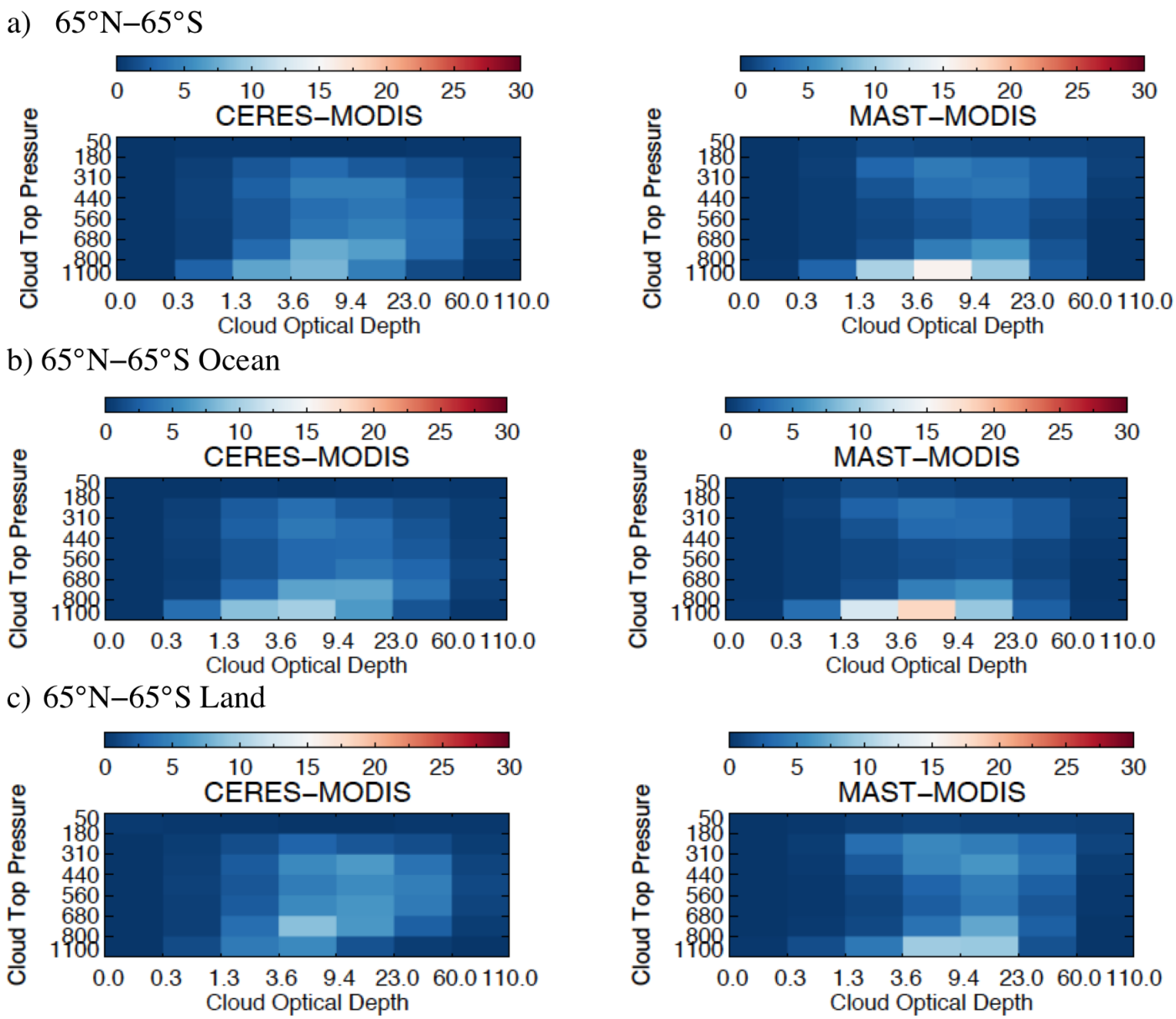


Figure 1

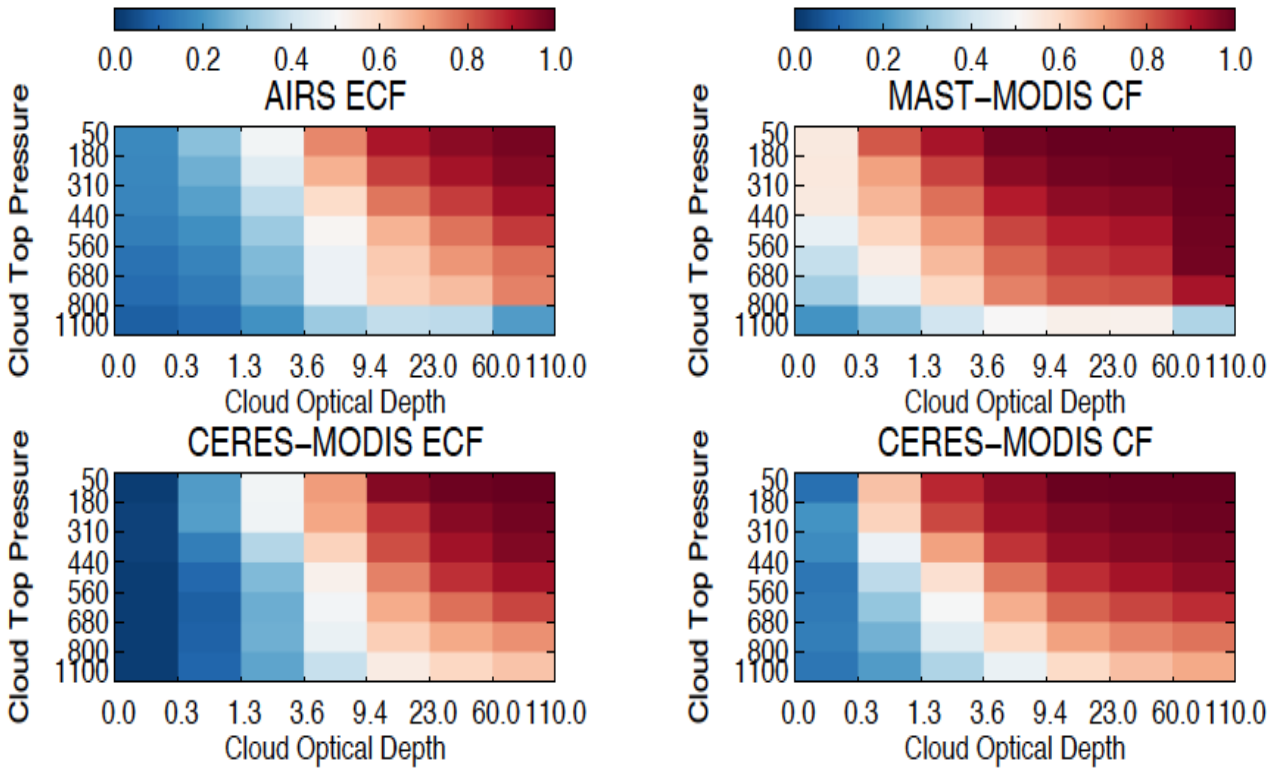
The Occurrence Frequency of Different Cloud Types on Cloud Histogram



Left: The CERES-MODIS retrieval (Minnis et al. 2011)

Right: The MODIS Atmospheric Science Team cloud retrieval (Platnick et al. 2003)

Cloud Fractions from Different Data and Methods



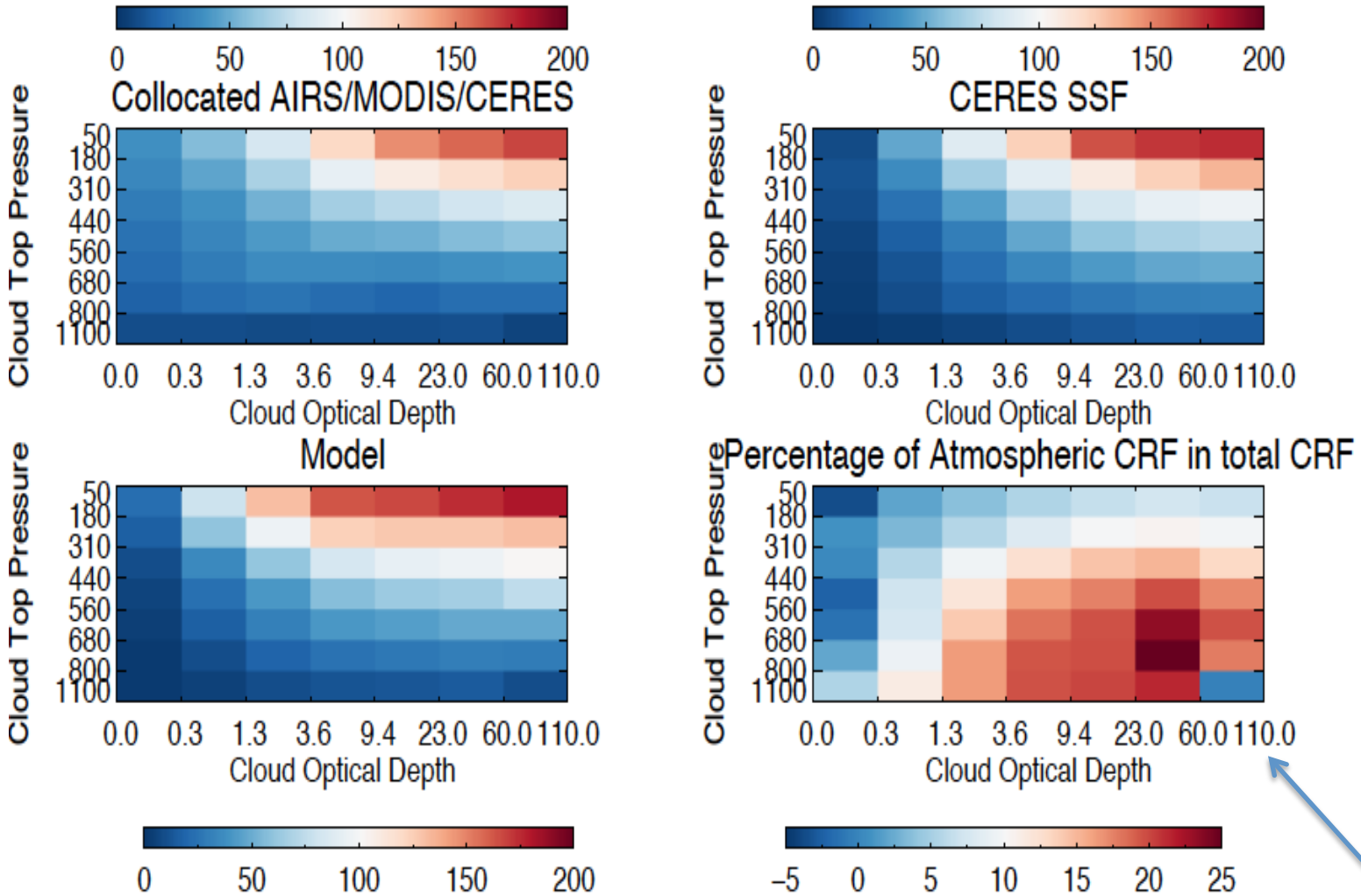
ECF: IR effective cloud fraction

CF: Cloud area fraction

Standard MODIS retrieval Collection 5:

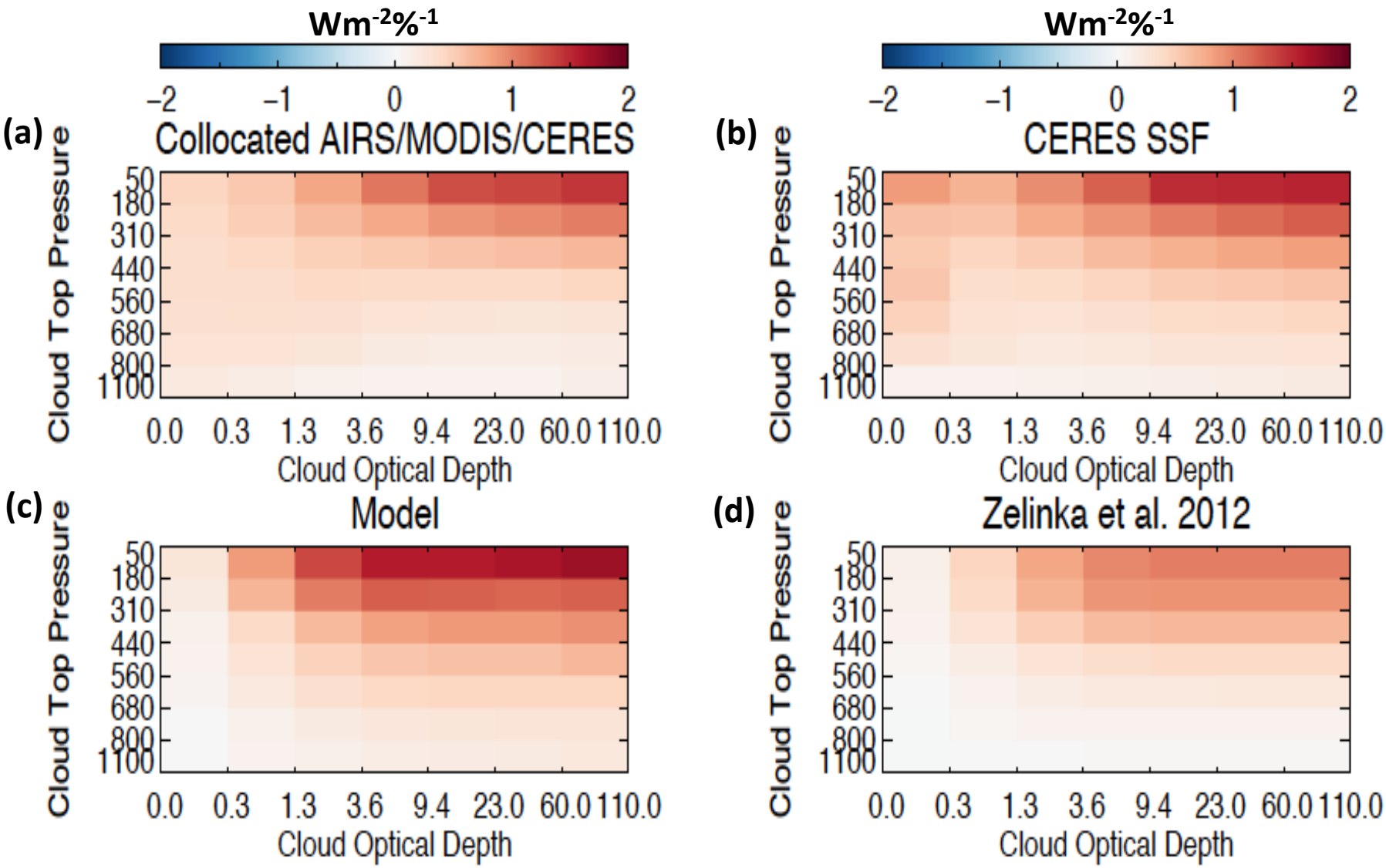
1) Retrieval of cloud optical depth and particle size is not performed for pixels with broken cloud and cloud edges
2) Missing of optically thin cloud (0.04)
3) Misplacement of low cloud under temperature inversion conditions.

Cloud Radiative Forcing from Observation and Off-line RTM

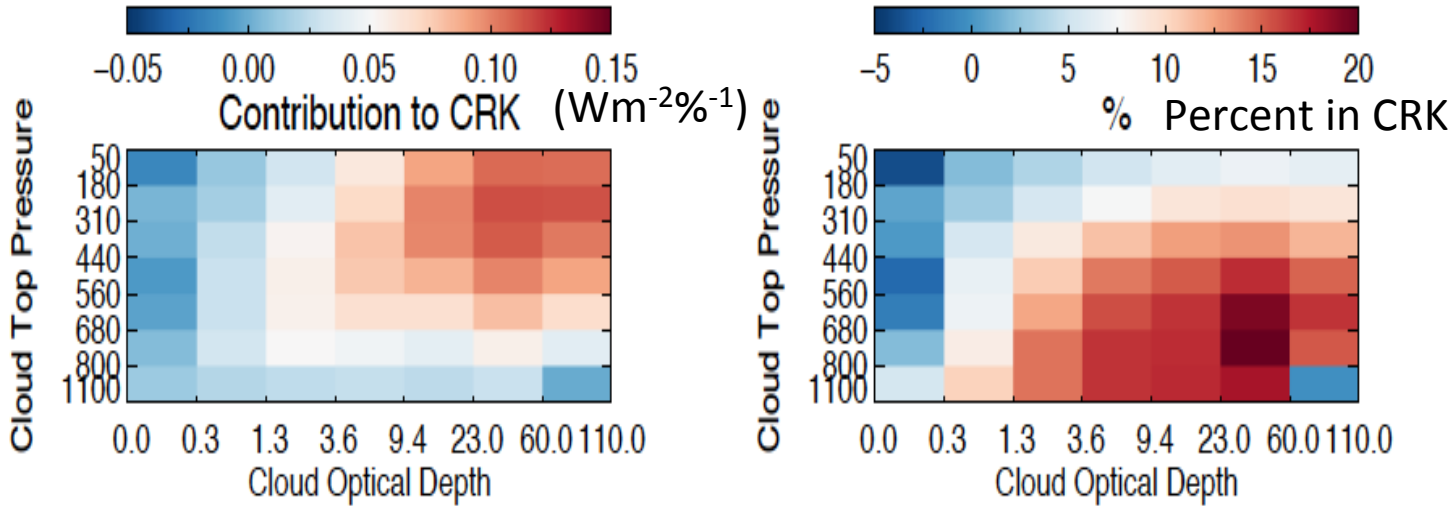


Large contribution from atmospheric CRF to total CRF

Cloud Radiative Kernels from Different Datasets and Methods

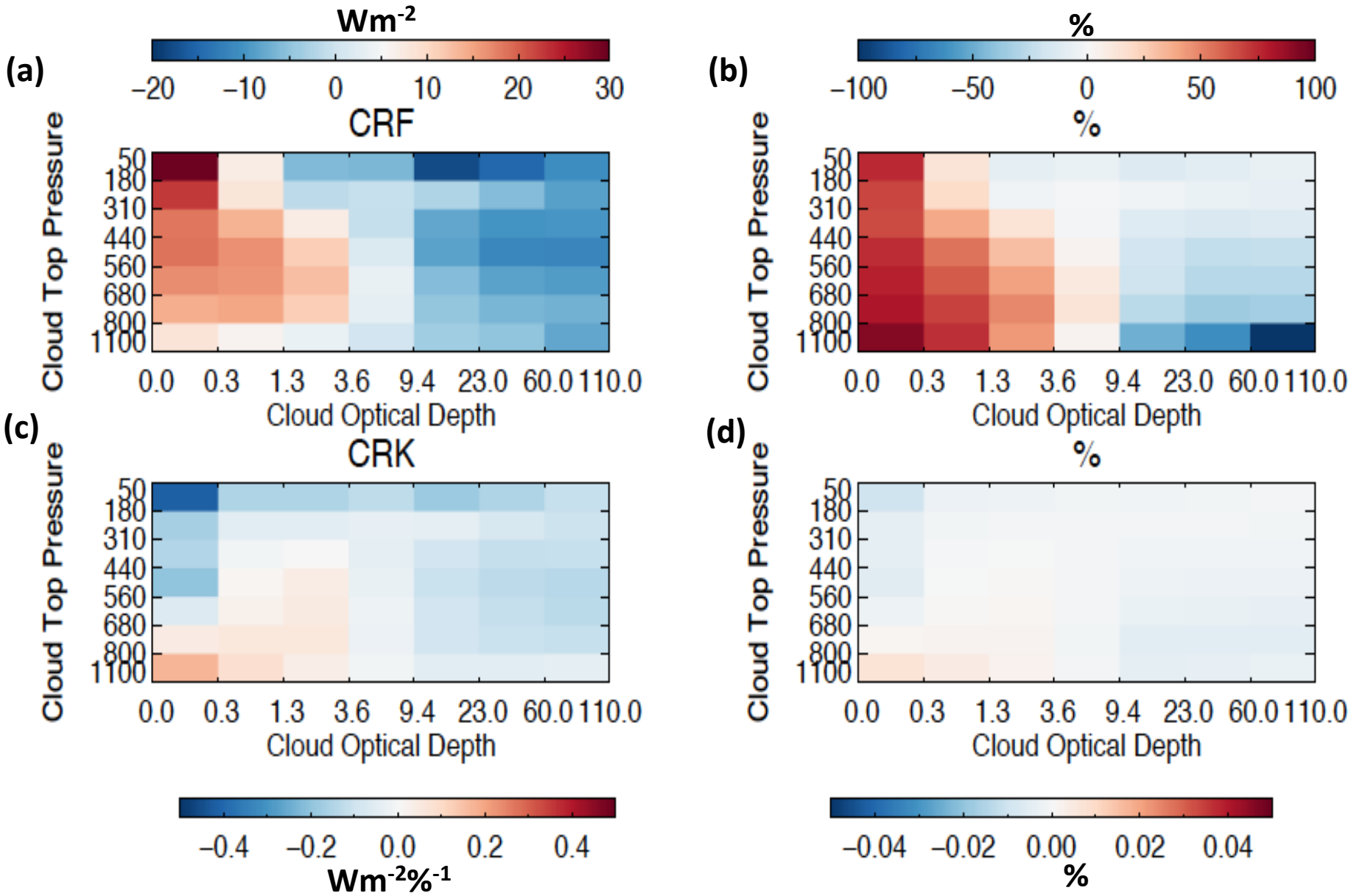


ACRF Contribution to Cloud Radiative Kernel



Large contribution from Atmospheric CRF, which can be removed with simple clear-sky radiative transfer calculation using observations on atmosphere and cloud type.

Uncertainty Due to Different MODIS Cloud Retrieval Algorithms



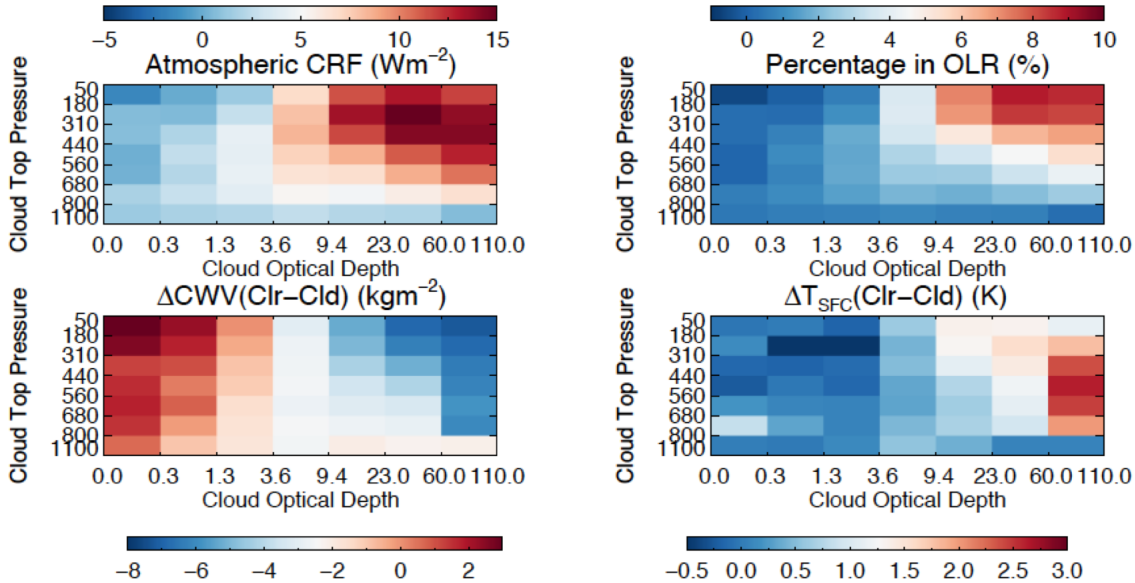
Summary

1. A method to derive cloud radiative kernel from observations only. The kernels are independent of model simulations and radiative transfer calculations.
2. The atmospheric cloud radiative forcing contributes less than 10% to total OLR, upto 25% of total CRF. If not removed, can cause upto 20% of uncertainty to CRK.
3. Different MODIS cloud retrieval algorithms largely affect the CRF magnitude by cloud type, but its impact on LW CRK is negligible (< +/-0.04%).
4. Different selection criteria for clear sky tested in this study and the inclusion of a vertical optical depth distribution in radiative transfer calculation both contribute very small uncertainties to longwave CRK calculation (0.001% and 0.005%).

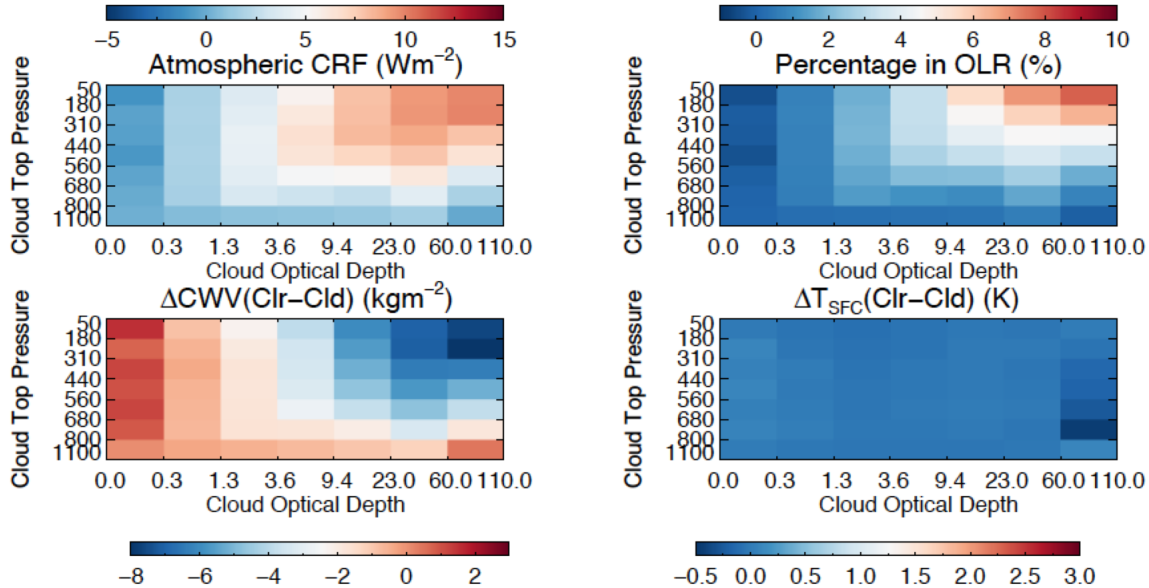
Atmospheric CRF and Its Contribution to Total OLR

- Over Ocean: depends on moisture difference between clear and cloudy conditions.
- Over Land: depends on both T_{SFC} and CWV differences.
- Contribution to OLR is less than 10%.

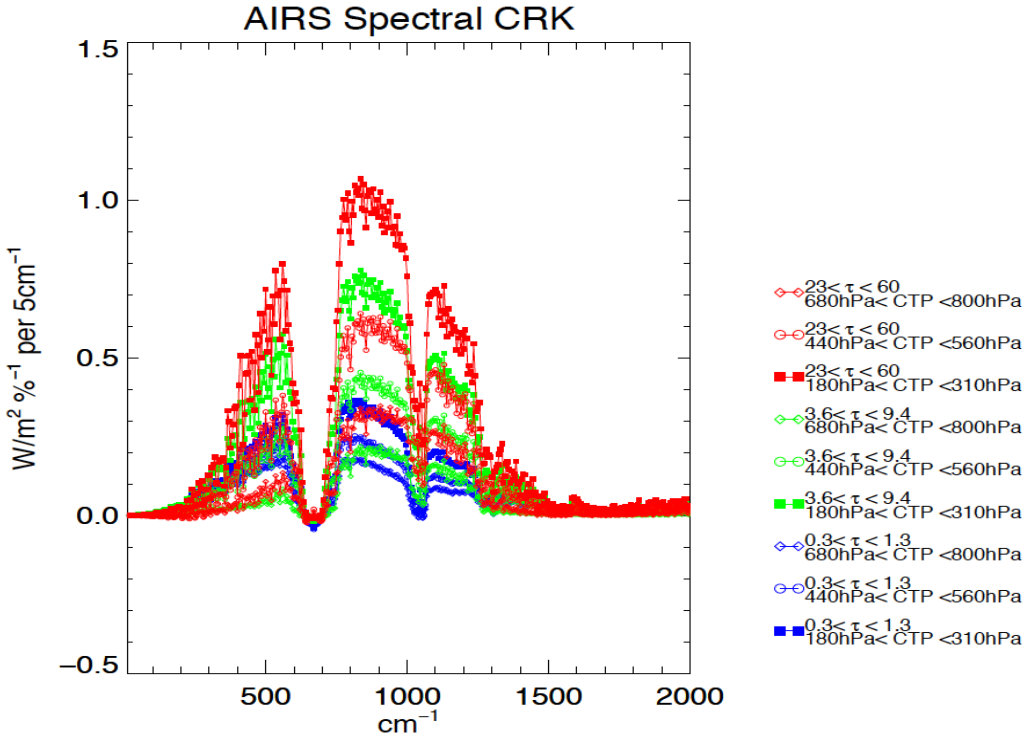
a) Over Land

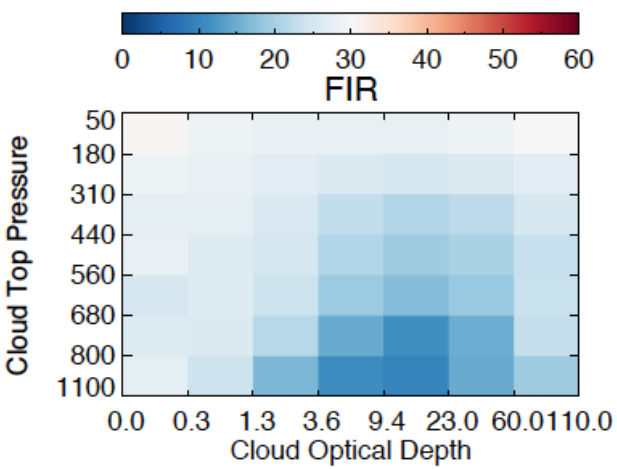


a) Over Ocean

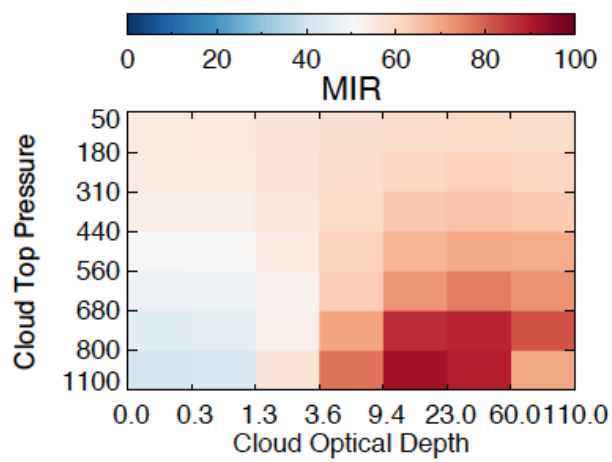


Spectral Cloud Radiative Kernel from AIRS Spectral OLR

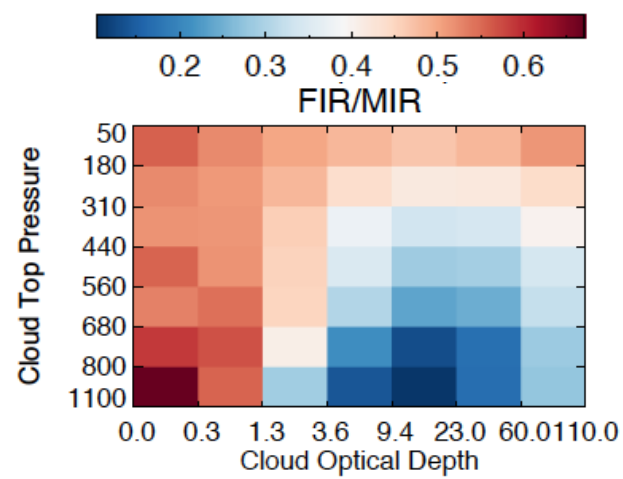




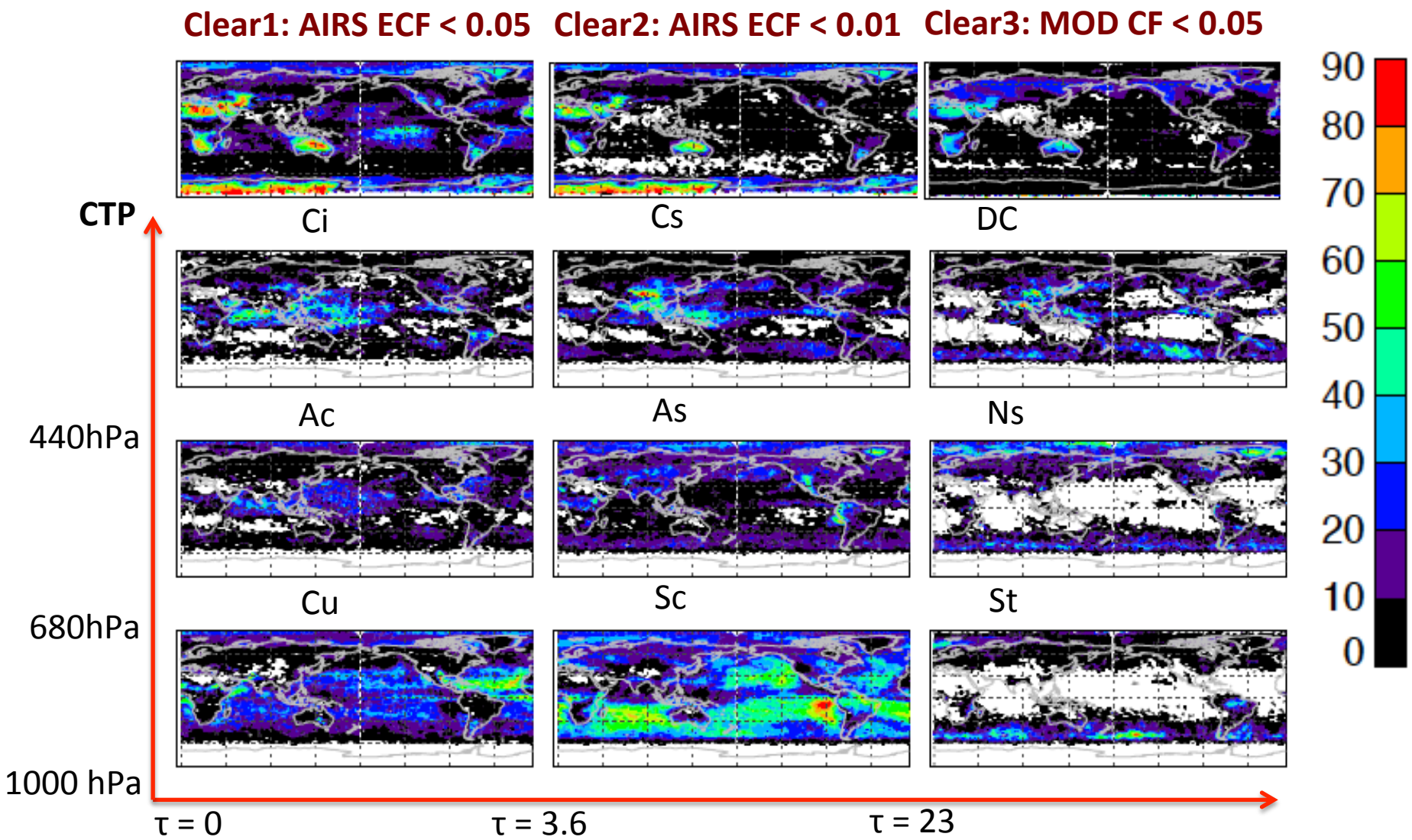
Far IR



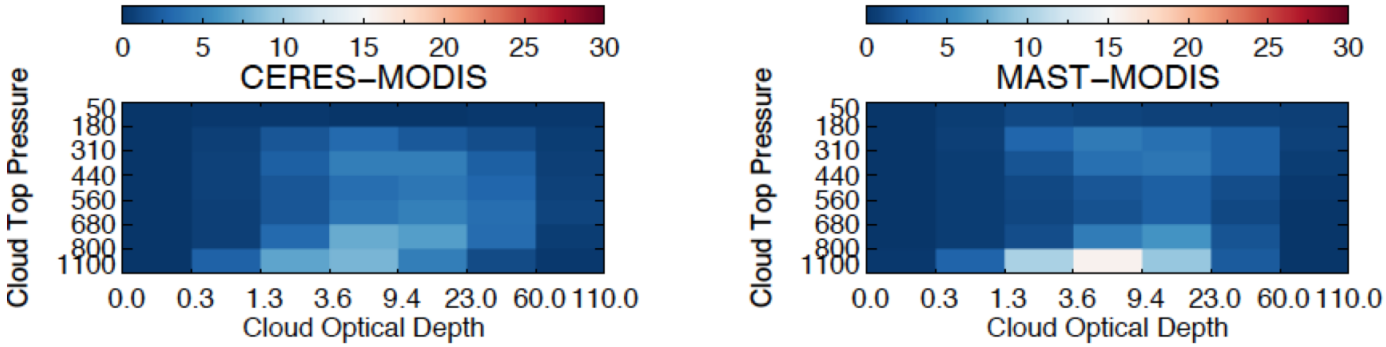
Middle IR



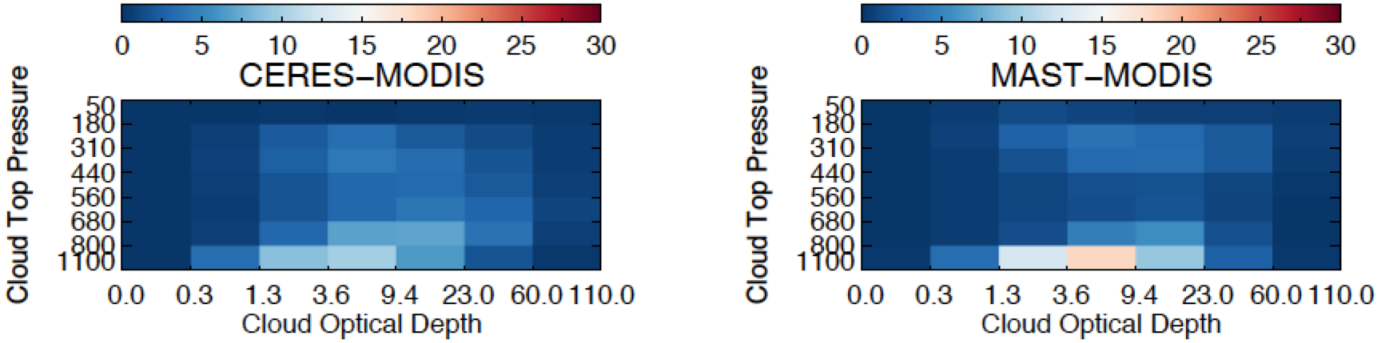
Ratio of FIR to MIR


Clear1: AIRS ECF < 0.05
Clear2: AIRS ECF < 0.01
Clear3: MOD CF < 0.05
CTP
Ci
Cs
DC
Ac
As
Ns
440hPa
Cu
Sc
St
680hPa
1000 hPa
τ = 0
τ = 3.6
τ = 23
90
80
70
60
50
40
30
20
10
0

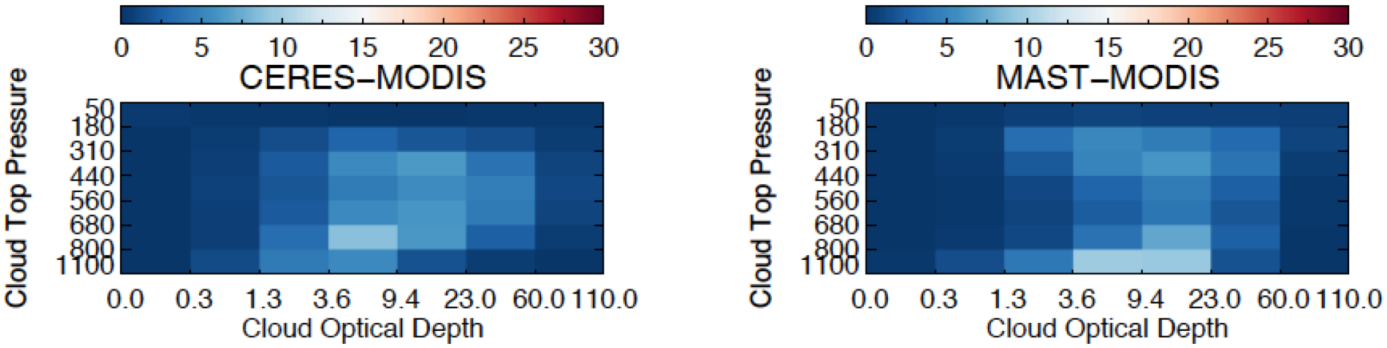
a) 65°N–65°S

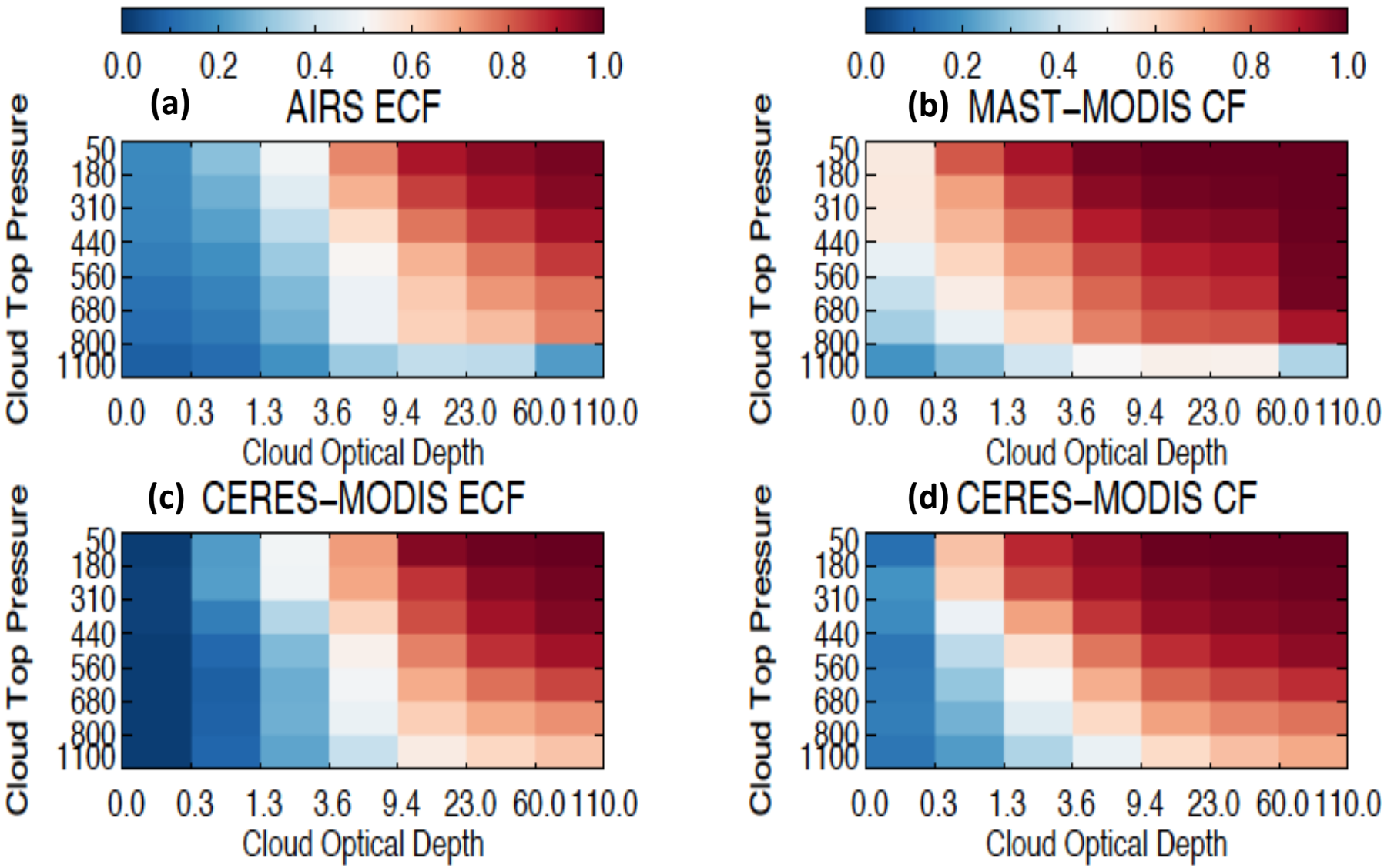


b) 65°N–65°S Ocean

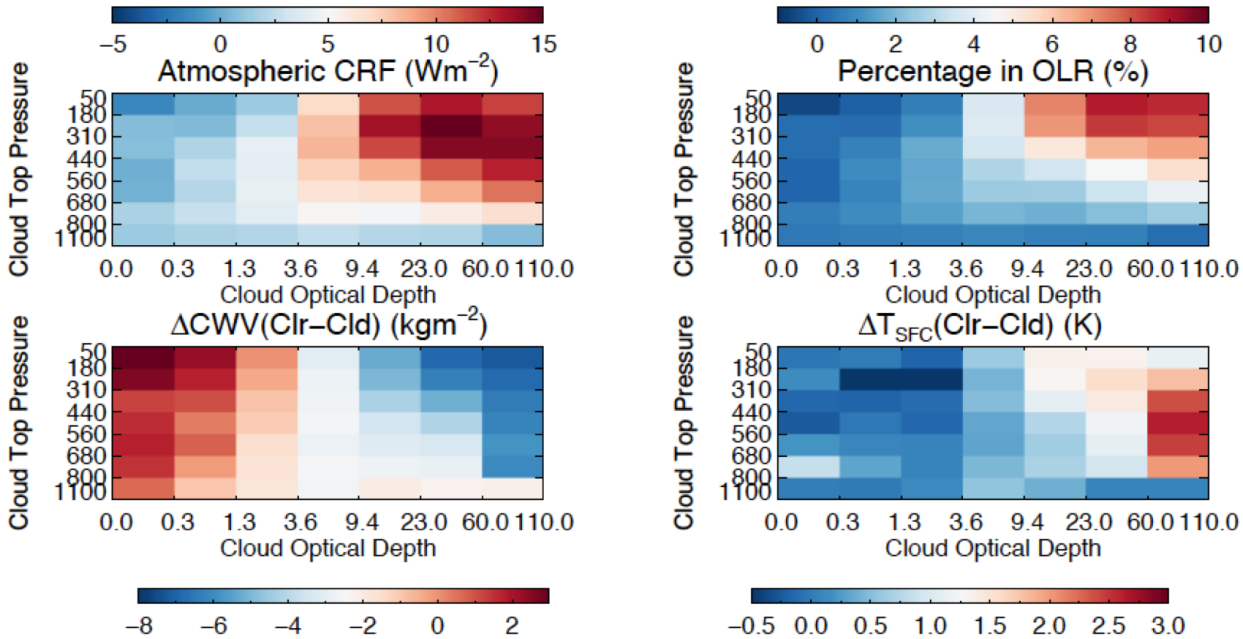


c) 65°N–65°S Land

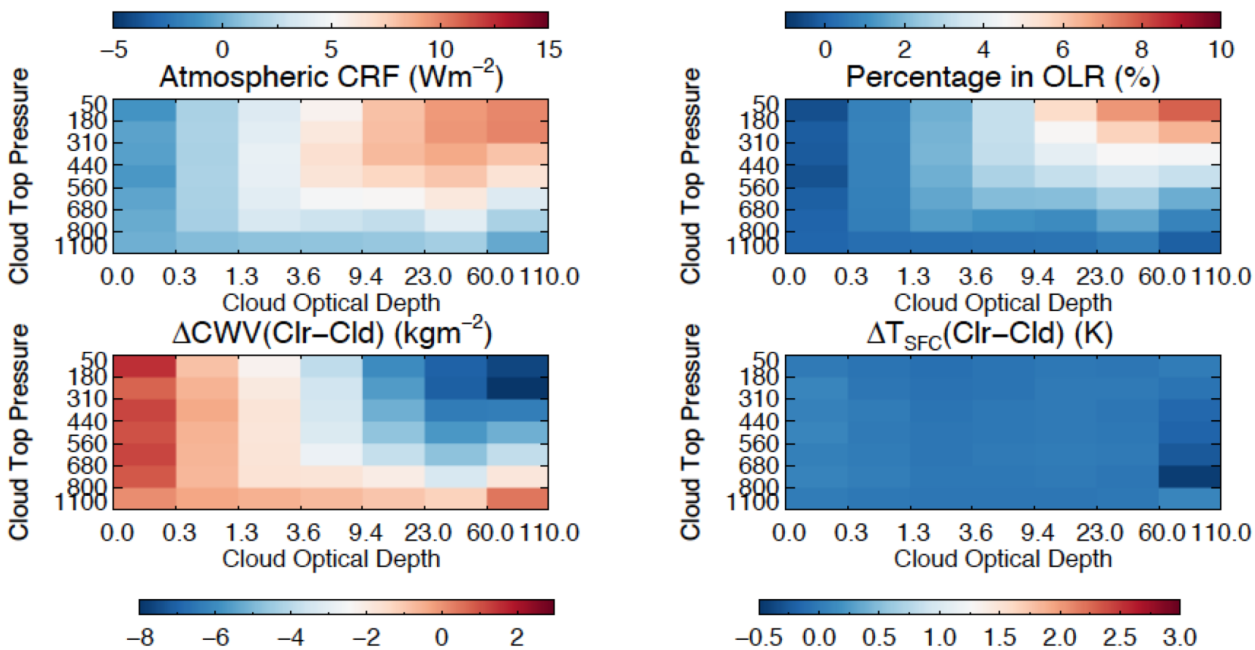


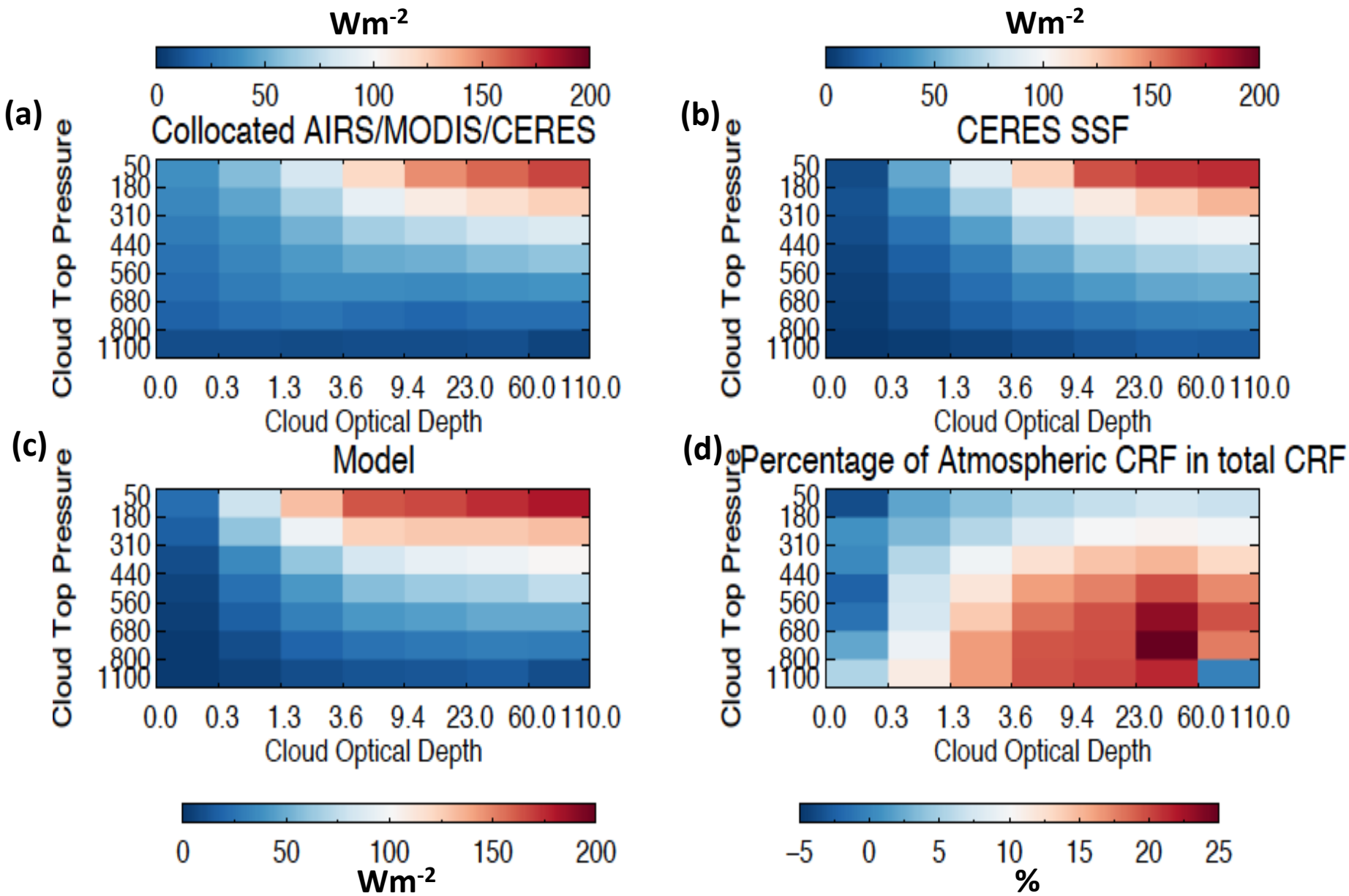

0.0 0.2 0.4 0.6 0.8 1.0
(a) AIRS ECF
(b) MAST–MODIS CF
(c) CERES–MODIS ECF
(d) CERES–MODIS CF
Cloud Top Pressure
50
180
310
440
560
680
800
1100
0.0 0.3 1.3 3.6 9.4 23.0 60.0 110.0
Cloud Optical Depth

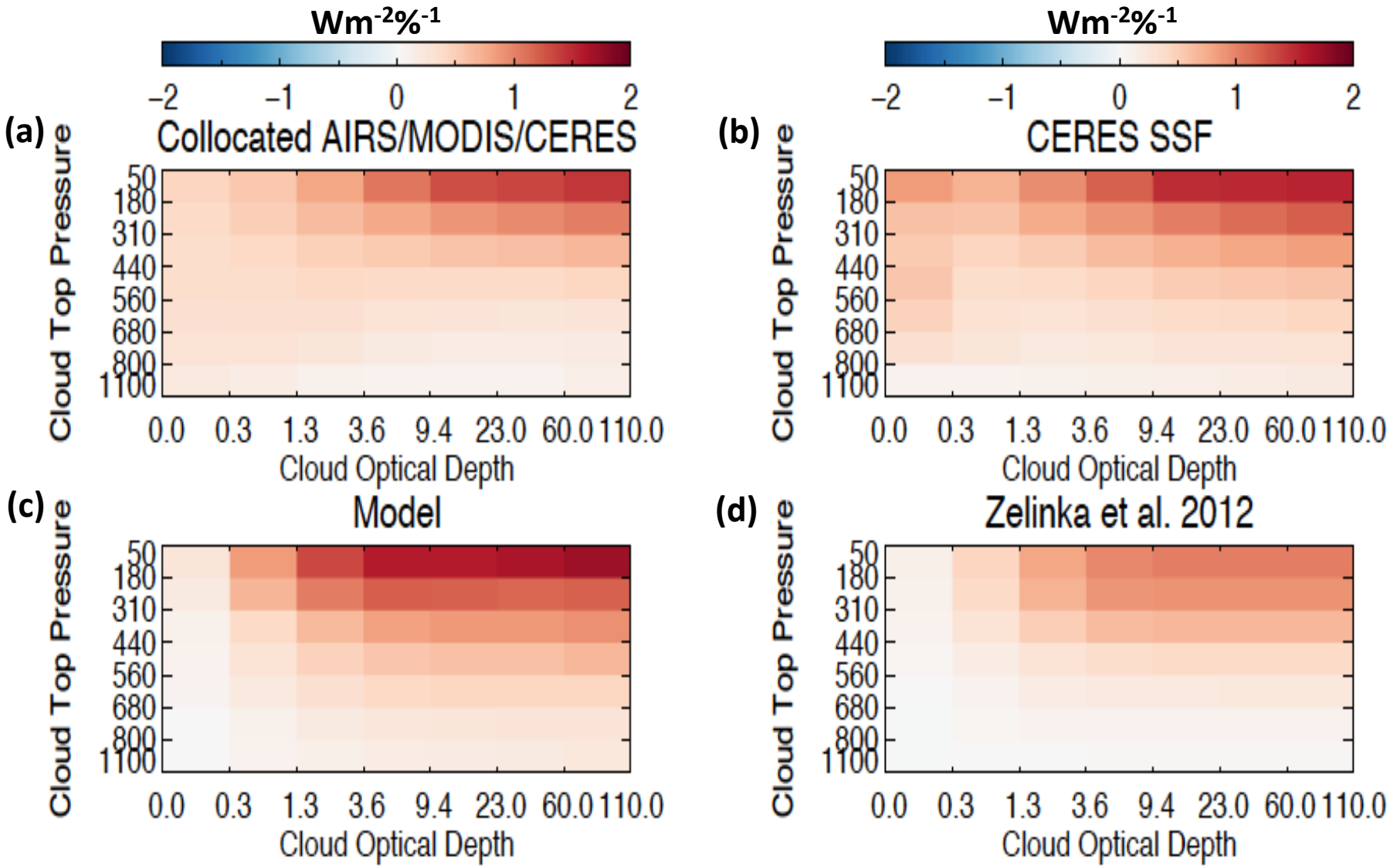
a) Over Land

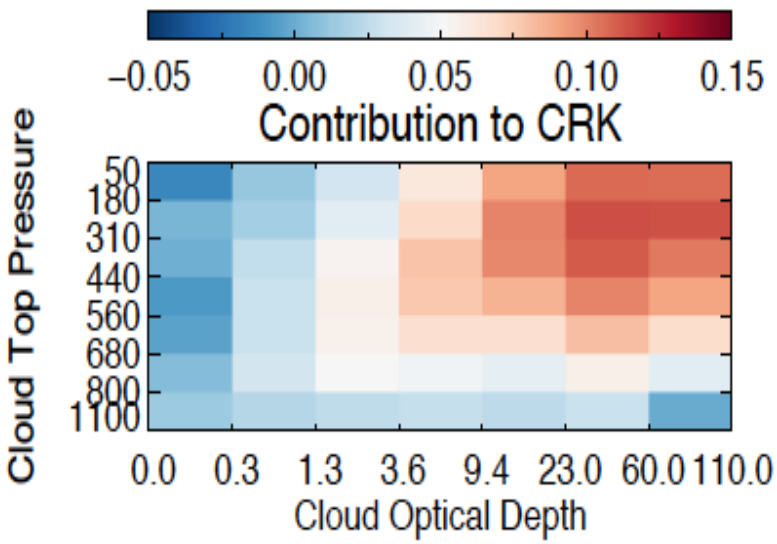


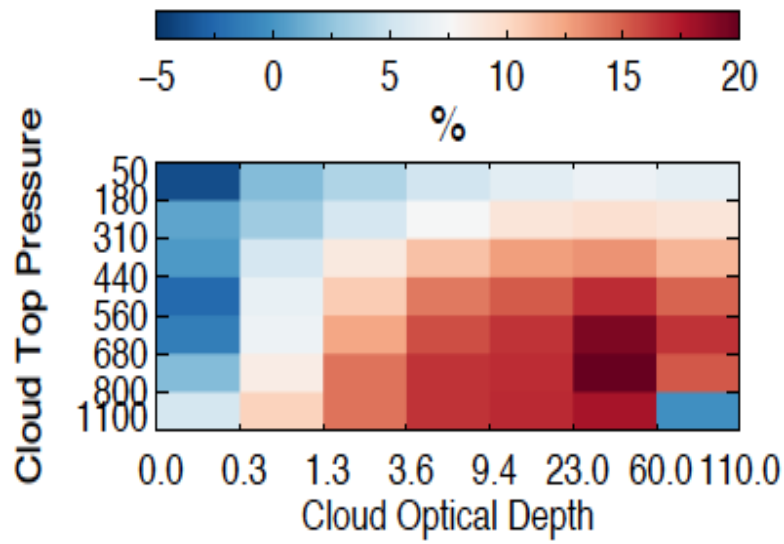
a) Over Ocean

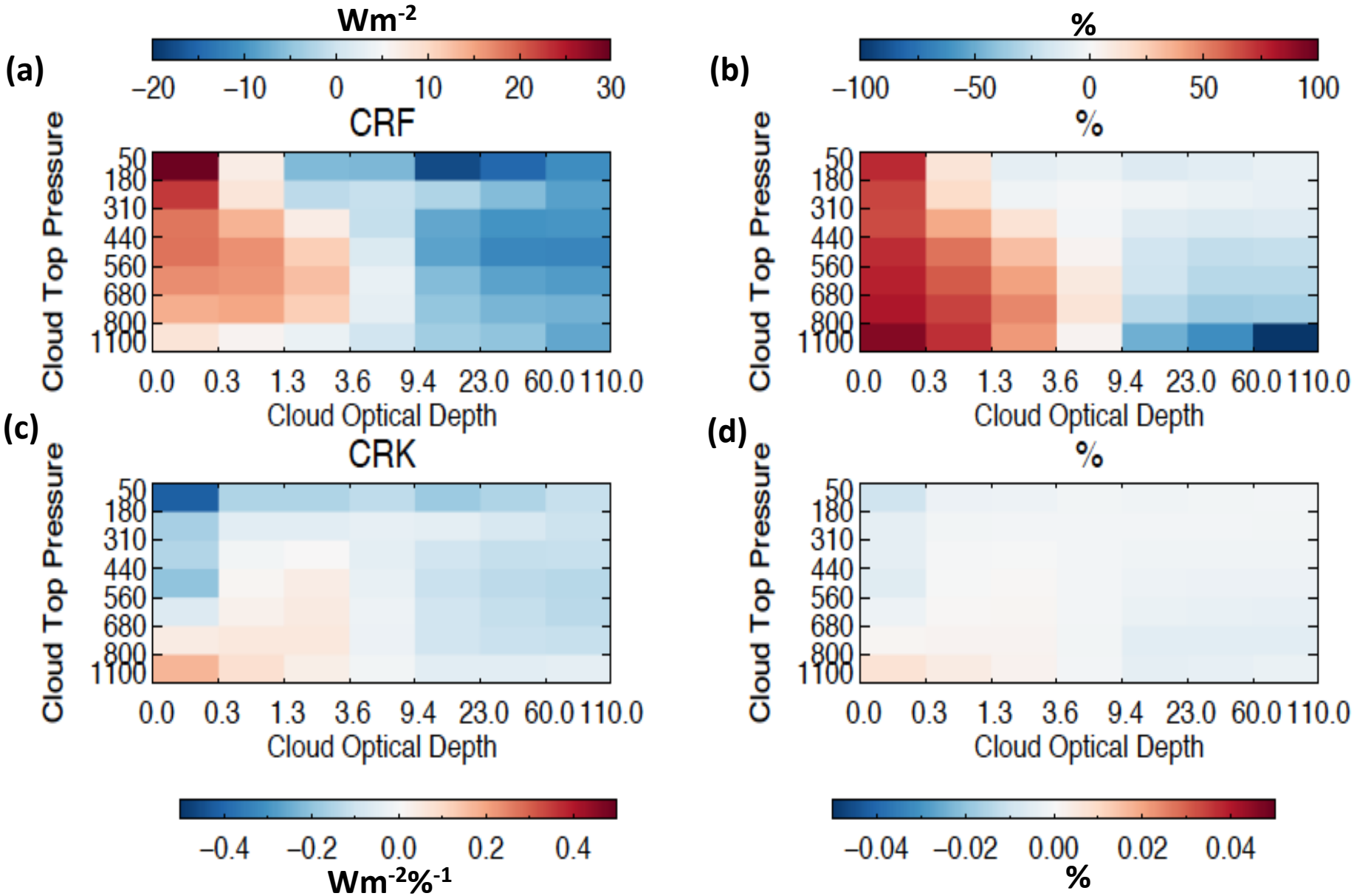


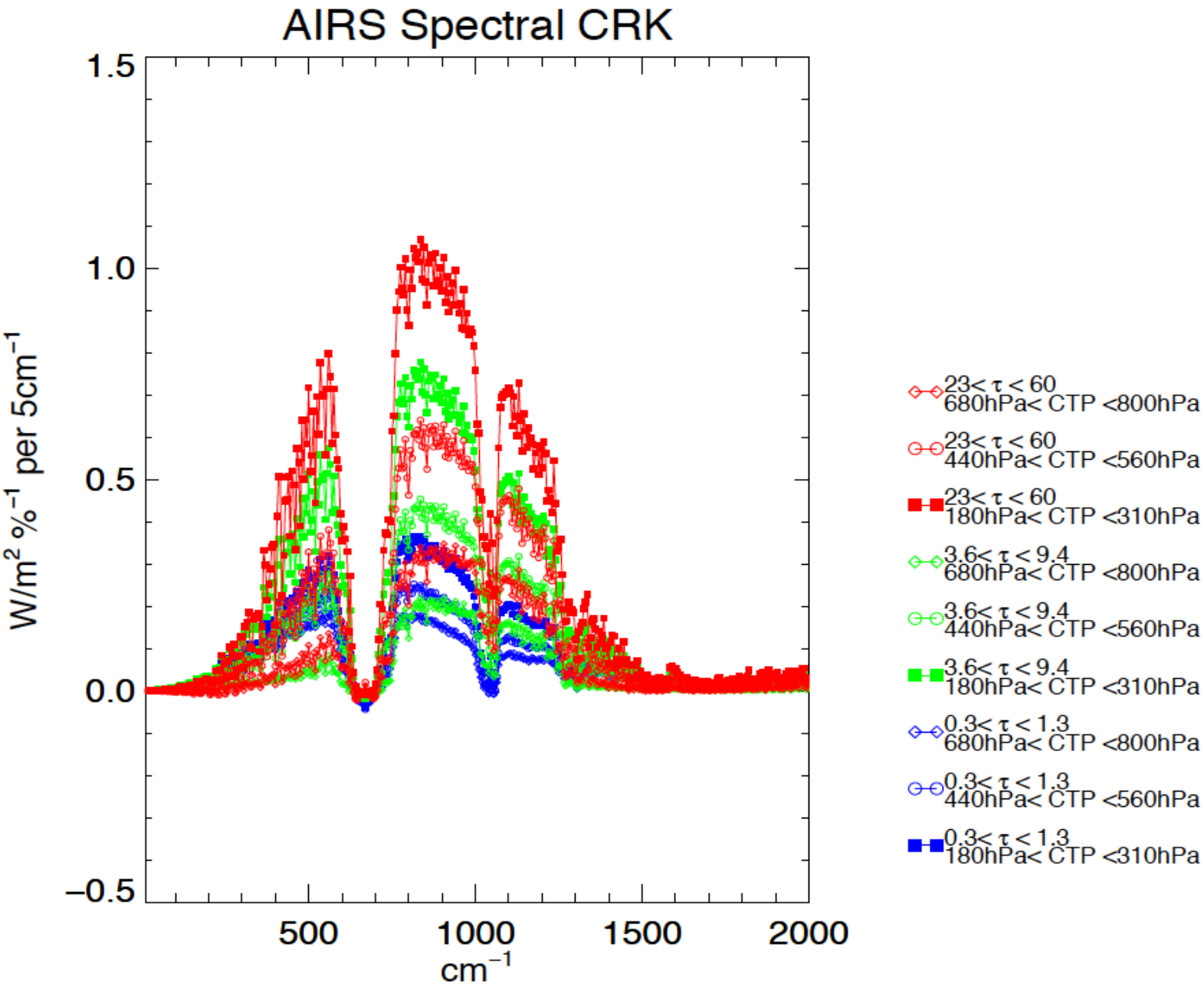

(a)
Collocated AIRS/MODIS/CERES
(b)
CERES SSF
(c)
Model
(d)
Percentage of Atmospheric CRF in total CRF
Cloud Top Pressure
50
180
310
440
560
680
800
1100
0.0 0.3 1.3 3.6 9.4 23.0 60.0 110.0
Cloud Optical Depth
Wm-2
0 50 100 150 200
%
−5 0 5 10 15 20 25

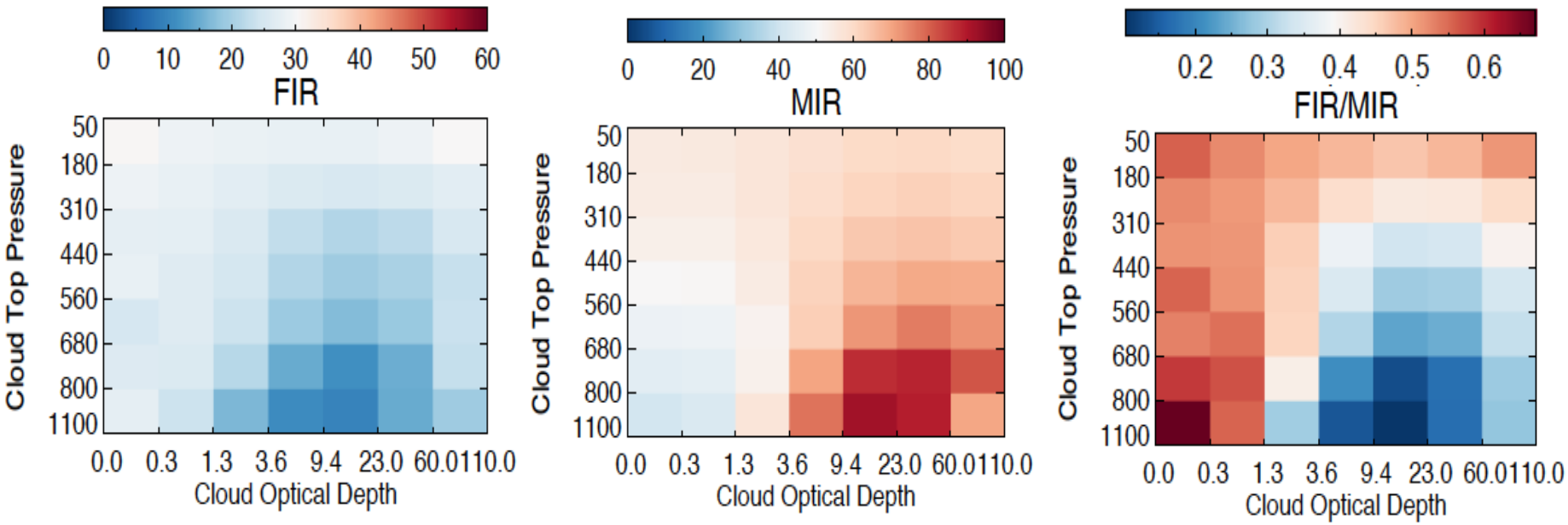

Wm-2%-1
−2
−1
0
1
2
(a)
Collocated AIRS/MODIS/CERES
(b)
CERES SSF
(c)
Model
(d)
Zelinka et al. 2012
Cloud Top Pressure
50
180
310
440
560
680
800
1100
0.0
0.3
1.3
3.6
9.4
23.0
60.0
110.0
Cloud Optical Depth


−0.05
0.00
0.05
0.10
0.15
Contribution to CRK
Cloud Top Pressure
50
180
310
440
560
680
800
1100
0.0
0.3
1.3
3.6
9.4
23.0
60.0
110.0
Cloud Optical Depth


−5
0
5
10
15
20
%
Cloud Top Pressure
50
180
310
440
560
680
800
1100
0.0
0.3
1.3
3.6
9.4
23.0
60.0
110.0
Cloud Optical Depth


(a)
Wm-2
−20 −10 0 10 20 30
CRF
Cloud Top Pressure
50 180 310 440 560 680 800 1100
0.0 0.3 1.3 3.6 9.4 23.0 60.0 110.0
Cloud Optical Depth
(b)
%
−100 −50 0 50 100
%
Cloud Top Pressure
Cloud Optical Depth
(c)
CRK
Cloud Top Pressure
Cloud Optical Depth
−0.4 −0.2 0.0 0.2 0.4
Wm-2%-1
(d)
%
Cloud Top Pressure
Cloud Optical Depth
−0.04 −0.02 0.00 0.02 0.04
%


AIRS Spectral CRK
1.5
1.0
0.5
0.0
−0.5
W/m² %⁻¹ per 5cm⁻¹
500
1000
1500
2000
cm⁻¹
23< τ < 60
680hPa< CTP <800hPa
23< τ < 60
440hPa< CTP <560hPa
23< τ < 60
180hPa< CTP <310hPa
3.6< τ < 9.4
680hPa< CTP <800hPa
3.6< τ < 9.4
440hPa< CTP <560hPa
3.6< τ < 9.4
180hPa< CTP <310hPa
0.3< τ < 1.3
680hPa< CTP <800hPa
0.3< τ < 1.3
440hPa< CTP <560hPa
0.3< τ < 1.3
180hPa< CTP <310hPa


0 10 20 30 40 50 60
FIR
Cloud Top Pressure
50 180 310 440 560 680 800 1100
0.0 0.3 1.3 3.6 9.4 23.0 60.0 110.0
Cloud Optical Depth
0 20 40 60 80 100
MIR
Cloud Top Pressure
50 180 310 440 560 680 800 1100
0.0 0.3 1.3 3.6 9.4 23.0 60.0 110.0
Cloud Optical Depth
0.2 0.3 0.4 0.5 0.6
FIR/MIR
Cloud Top Pressure
50 180 310 440 560 680 800 1100
0.0 0.3 1.3 3.6 9.4 23.0 60.0 110.0
Cloud Optical Depth