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Improvement of Shortwave Radiation Budget by Three-Dimensional Scene Construction Algorithm (SCA)

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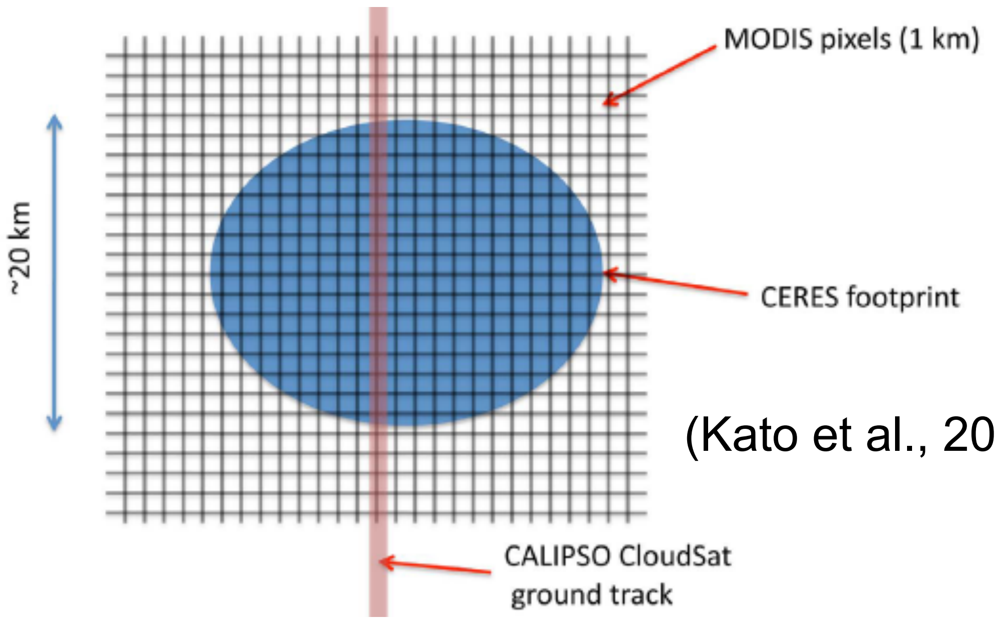
Backgrounds

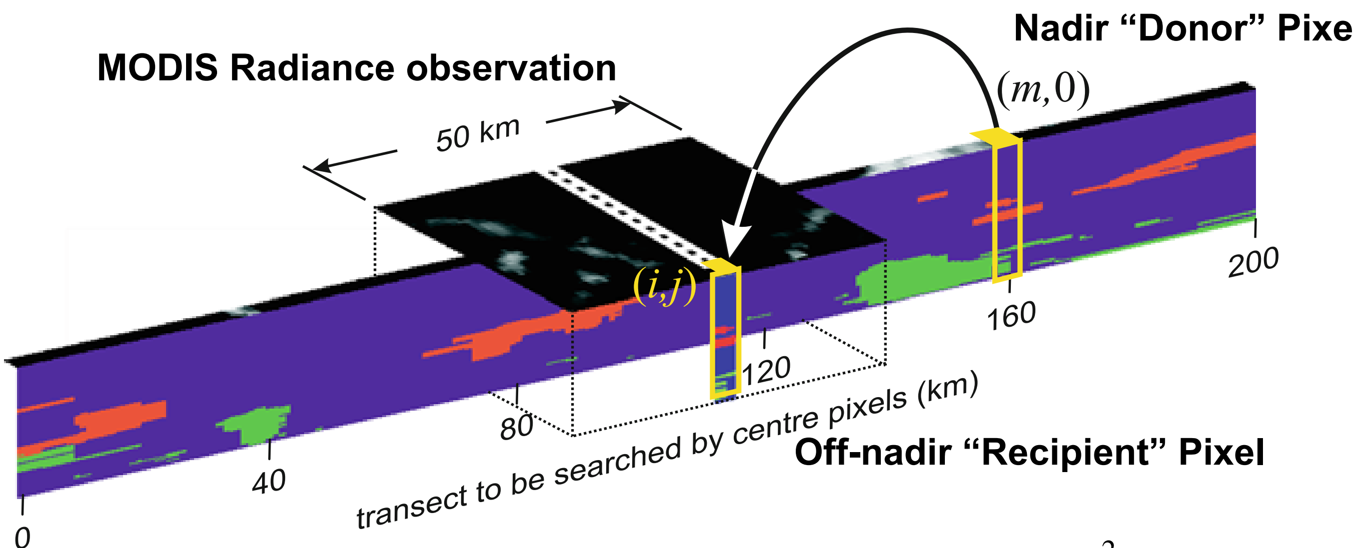
- Active sensors such as CloudSat and CALIPSO provide more accurate and detailed cloud vertical information than passive sensor but their information is limited to narrow (~ 1 km) satellite ground track.
- Size of CERES footprint is ~20 km, and only part of the footprint is covered by active sensor measurements.
- CCCM products provide theoretical irradiance profiles from enhanced cloud products by integrating CALIPSO, CloudSat, and MODIS, but the cloud information comes from ground track portion within CERES footprint.



(Kato et al., 2011)

Scene Construction Algorithm (SCA) (Barker et al., 2011, QJRMS)

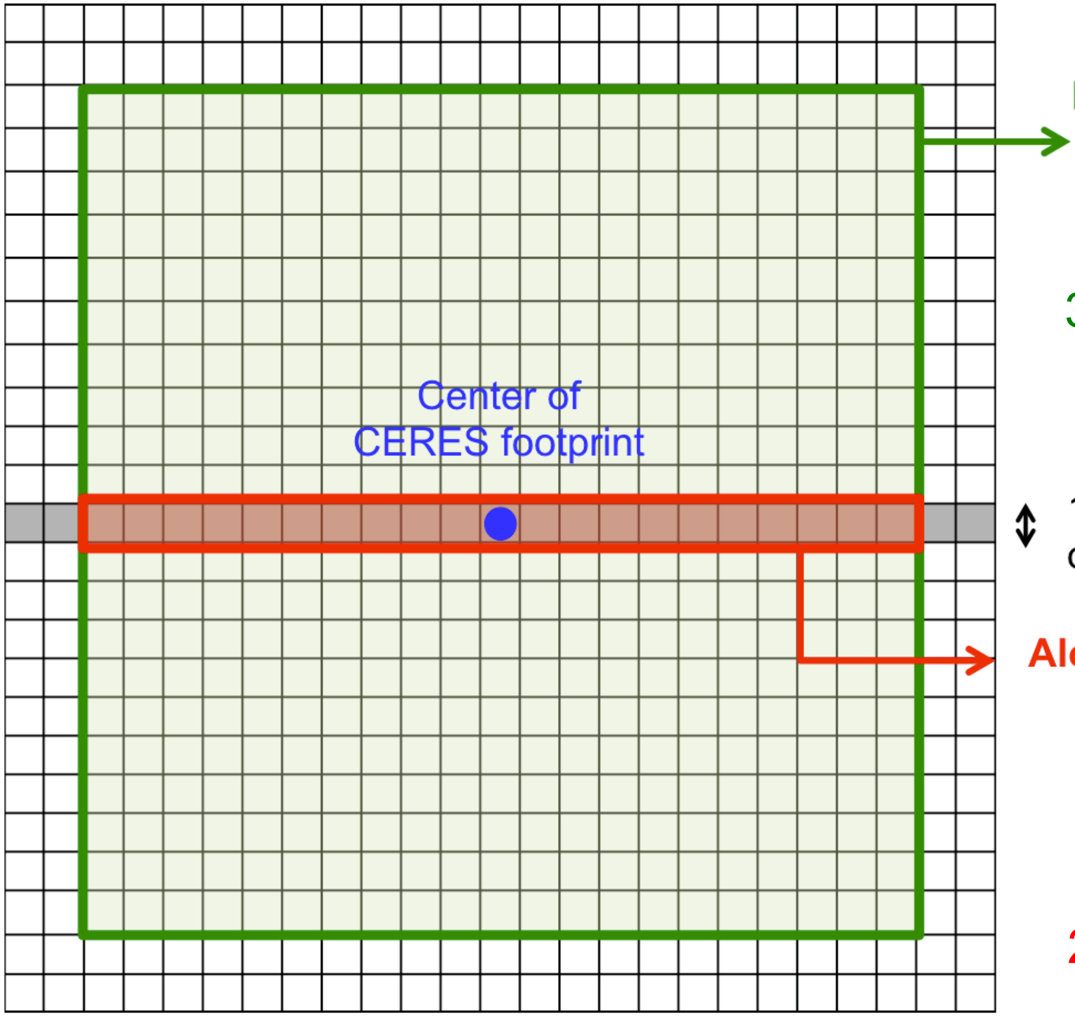
"2D Atmosphere → 3D Atmosphere"



$$F(i,j;m)=\sum_{i=1}^{4}\left[\frac{r_k(i,j)-r_k(m,0)}{r_k(i,j)}\right]^2,\quad m\in[i-100,i+100]$$

Cloud properties between two close pixels are similar if the two pixels have similar TOA radiances at multiple channels, given that atmospheric and surface conditions do not vary too much (Barker et al., 2011).

Two Types of Coverage of CERES Field-of-View (FOV)



"With SCA"

Full coverage of CERES field of view (FOV): Surrounding 21 x 21 MODIS pixels

3D cloud information

1-km resolution of CCCM grids

Along track (AT) coverage within CERES FOV: Surrounding 21 x 1 MODIS pixels

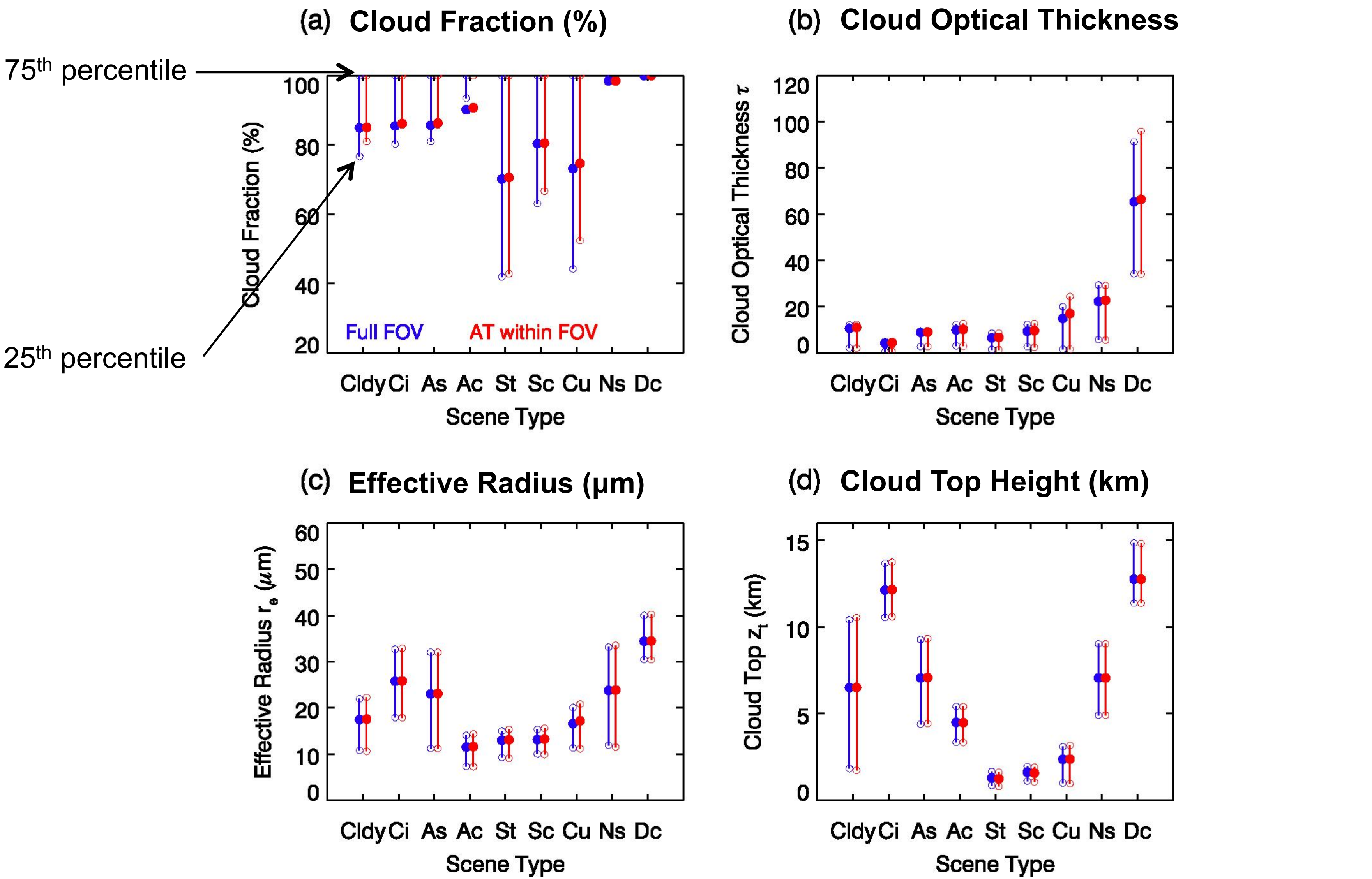
"Without SCA"

2D cloud information

Objectives

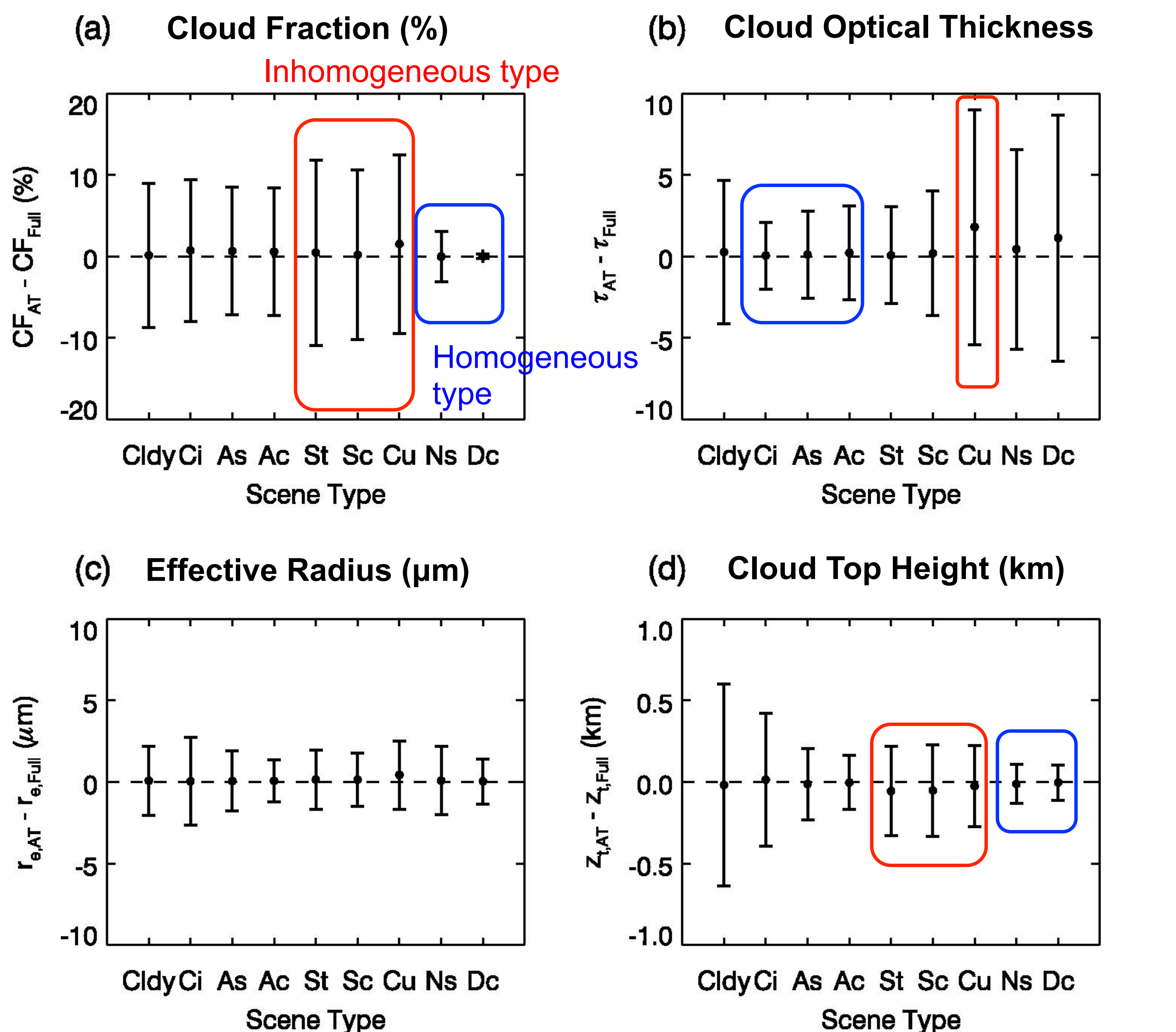
1. Apply cloud scene construction algorithm (SCA) to integrated 2D cloud properties obtained from CALIPSO, CloudSat, and MODIS, in order to obtain 3D cloud properties
2. Examine difference of the cloud properties over full CERES footprint (3D cloud) and over satellite-track portion within CERES footprint (2D cloud)
3. Simulate top-of-atmosphere (TOA) radiance with and without SCA atmosphere and compare these with CERES observation
4. Examine importance of SCA atmosphere on surface irradiance and absorbed irradiance by atmosphere
5. Finally, examine how SCA can improve simulation accuracy of shortwave radiance and irradiance in CERES products

Cloud Properties Obtained for Full and Along-track (AT) Coverages of CERES Footprint



	All	Ci	As	Ac	St	Sc	Cu	Ns	Dc
# of FOVs	156610	6603	6116	1076	7718	34538	680	5124	1289

Different Cloud Properties Obtained in Full and Along-track Coverages of CERES Footprint



Radiative Simulation Method

- Radiative transfer model
  Intercomparison of 3D Radiation Code (I3RC) Community Monte Carlo Model (Cahalan et al., 2005; Pincus and Evans, 2009)

- Input parameters
  - Ocean surface albedo model (Jin et al., 2004), which is a function of solar zenith angle
  - Gas absorption from correlated-k-distribution method (Kato et al., 1999) with Mid-latitude summer (MLS) profile (McClatchey et al., 1972)
  - Rayleigh scattering from MLS pressure and temperature profiles
  - Aerosol is ignored.
  - The number of photons: total column number x 10,000
  - Horizontal resolution: 1 km CCCM grid
  - 1D Independent column approximation (ICA) method (vertically moving photons) or 3D radiative transfer method (horizontally and vertically moving photons)

- Analysis of simulation results
  - 1-km horizontal resolution of simulation results are averaged for each CERES footprint (21 by 21 pixels or 21 by 1 pixels)
  - CERES footprints over ocean are only analyzed.

Angular Correction of Nadir Radiance in 3D Method

- ❖ Oblique radiance (viewing zenith angle >0) in 3D simulation results is hard to be matched with 1D ICA simulation results or CERES measurements due to shift of cloud location in 3D method.
- ❖ Therefore, the oblique radiance is inferred from nadir radiance in 3D method.

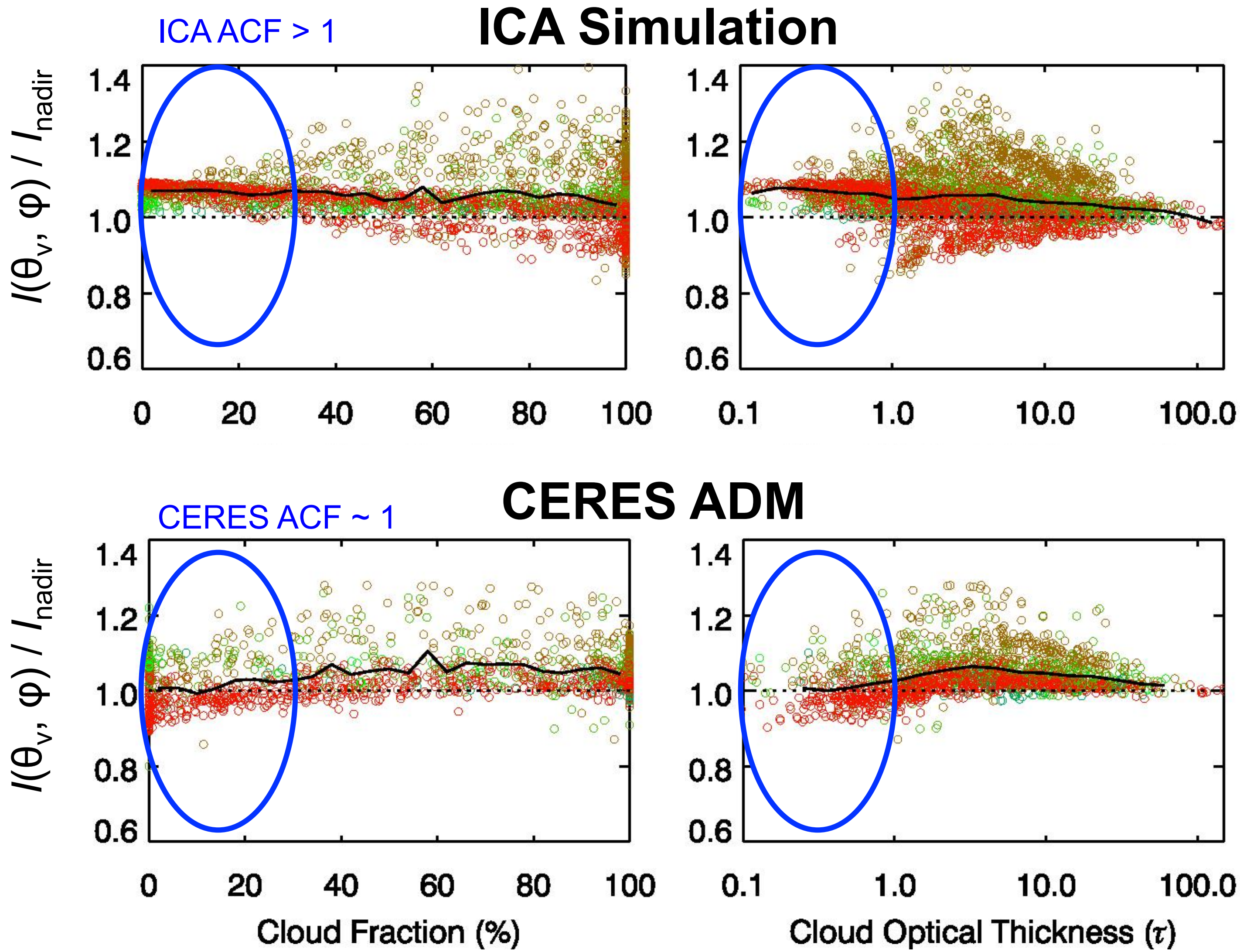
Step1: Angular correction factor is obtained either from 1D ICA simulation or CERES angular distribution model (ADM):

$$M(\theta_v, \varphi) = I(\theta_v, \varphi) / I_{nadir}$$

Step 2: Oblique radiance is obtained by multiplying angular correction factor to 3D nadir radiance.

$$I_{3D}(\theta_v, \varphi) = I_{nadir,3D} \, M(\theta_v, \varphi)$$

Angular Correction Factor



For broken clouds, $I(\theta_v, \varphi) / I_{nadir} = 1$ in CERES ADM and $I(\theta_v, \varphi) / I_{nadir} > 0$ ICA simulation because

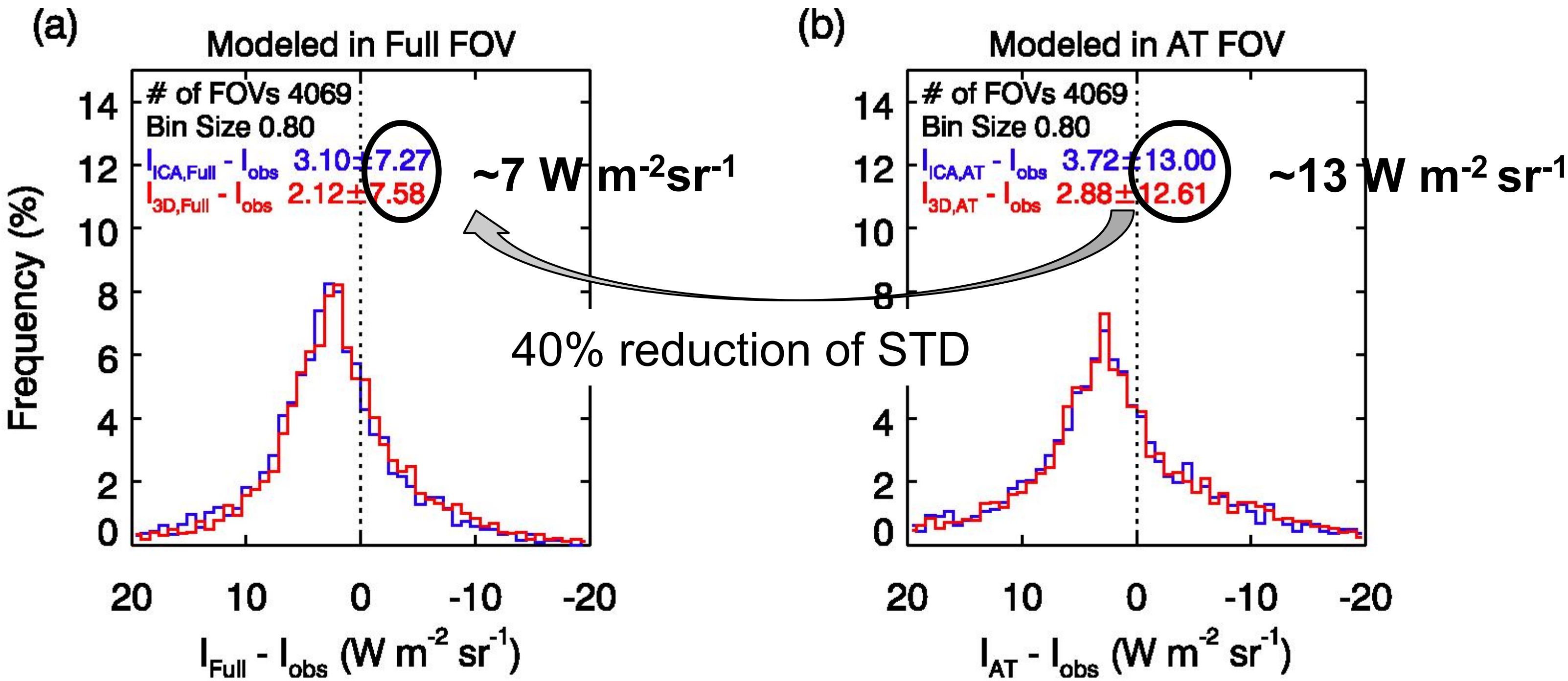
(1) Aerosol is ignored in ICA simulation

(2) Surrounding cloudy pixels change angular correction factor in CERES observation

Radiative Closure with CERES Observation

Simulation over Full CERES footprint

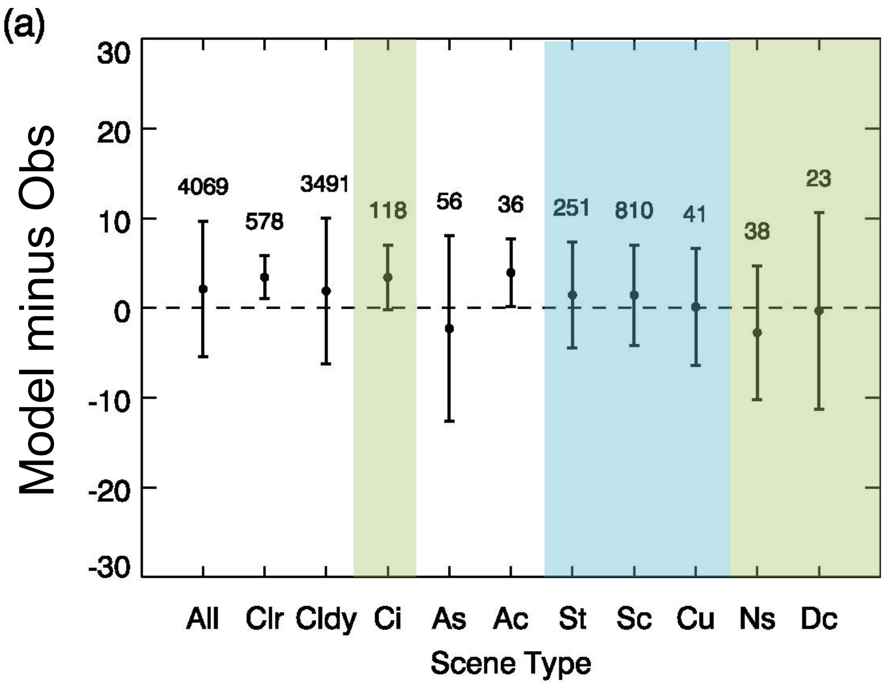
Simulation over Along-Track (AT) within CERES footprint



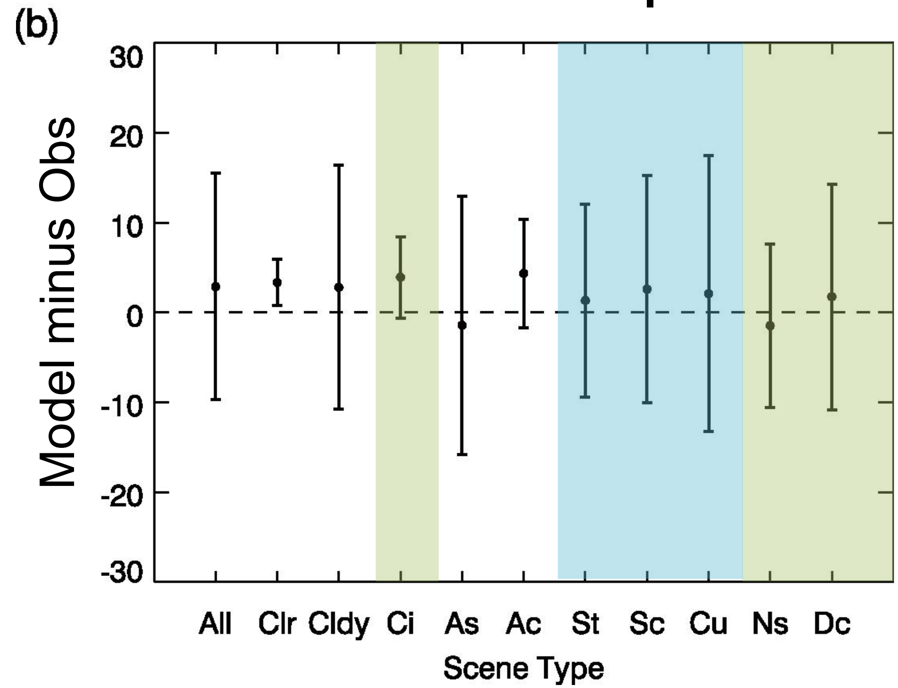
- Instantaneous difference between ICA and 3D or full and AT modeling results are much larger than the mean difference.
- Difference between full and AT modeling results is much larger than the difference between ICA and 3D methods.
- Slight positive modeling bias is partly due to uncertainty of modeling or CERES instrumental error.

Cloud-Type Dependency of Modeling Accuracy (Simulation minus Observation)

Simulation over full CERES footprint



Simulation over along-track (AT) portion of CERES footprint



Homogeneous cloud types in terms of small variation of cloud optical thickness or cloud fraction within CERES footprint

Inhomogeneous cloud types in terms of large variation of cloud optical thickness or cloud fraction within CERES footprint

3D Cloud Information Improves Simulation of TOA Radiances... How about 3D Radiative Transfer Then?

- Even if we know 3D cloud information, we may need to run 1D radiative transfer model under independent column approximation (ICA) assumption because 3D radiative transfer modeling takes time and requires huge computer sources.
- The impact of 3D cloud information can be compared to impact of 3D radiative process as follows:

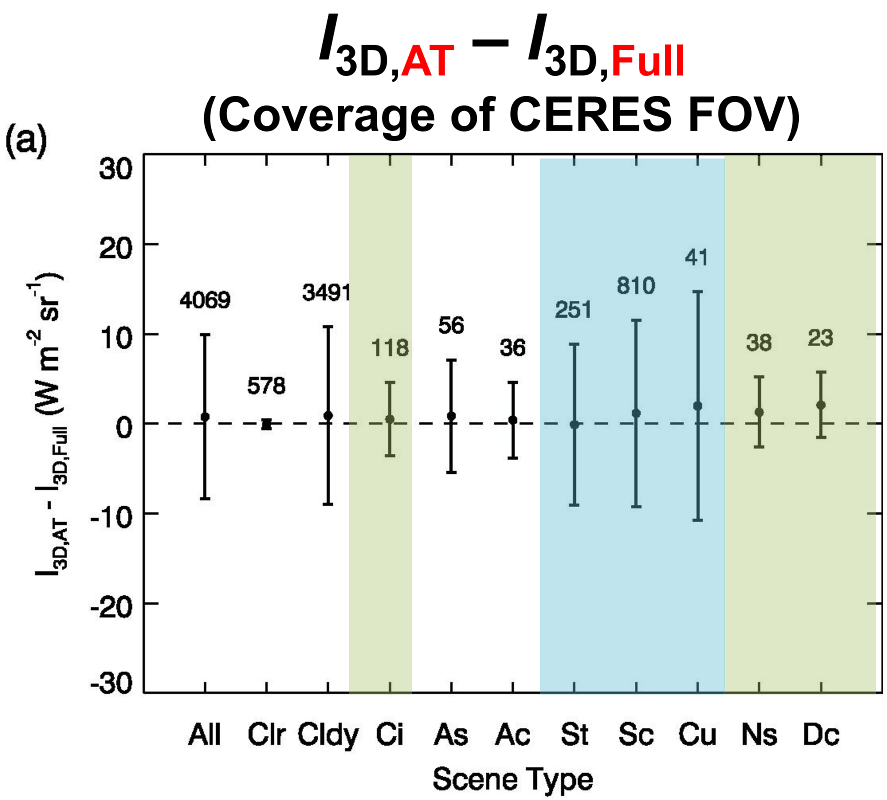
"Impact of SCA (3D information)" $I_{AT} - I_{Full}$

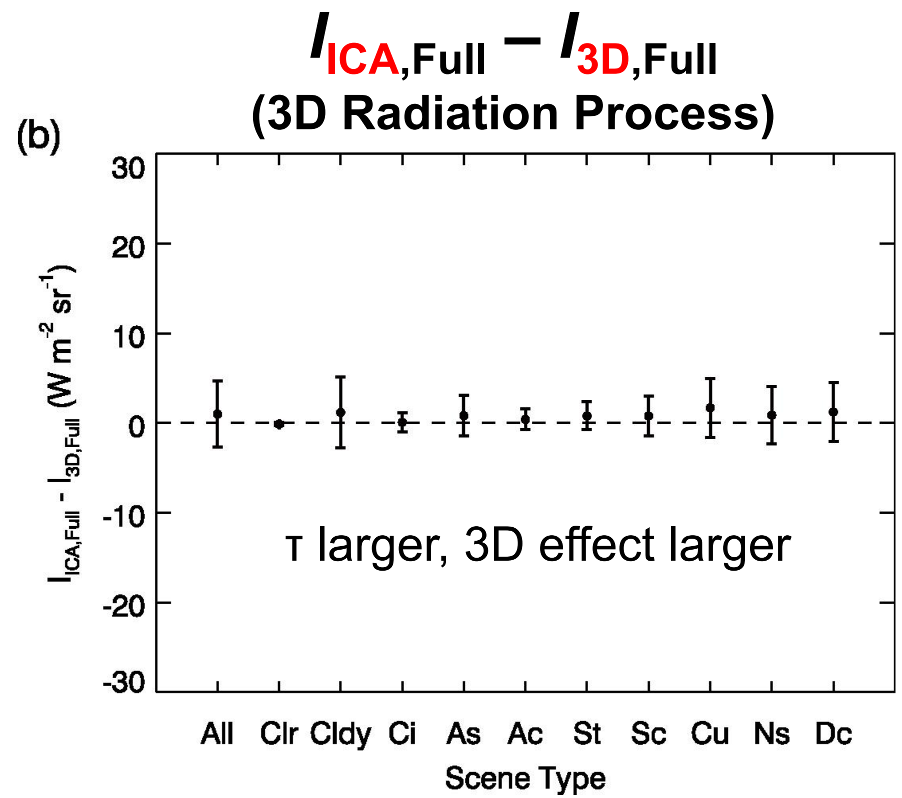
[2D atmosphere] – [3D atmosphere]

"Impact of 3D radiative process" $I_{1D} - I_{3D}$

[1D radiative transfer] – [3D radiative transfer]

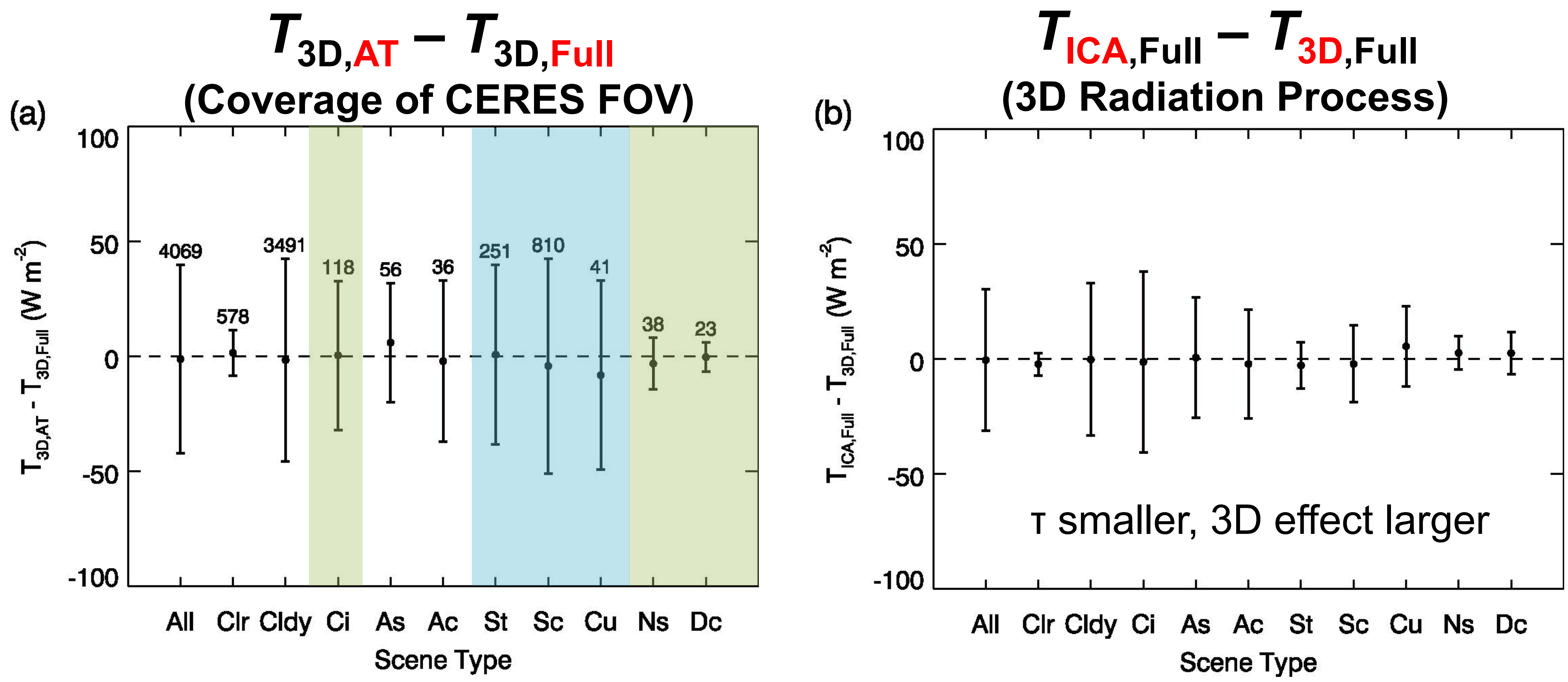
SCA versus 3D Radiation Process on TOA Radiance (Model-to-Model Difference)





- Impact of SCA 3D atmosphere on the TOA radiance is more important than that of 3D radiative transfer.

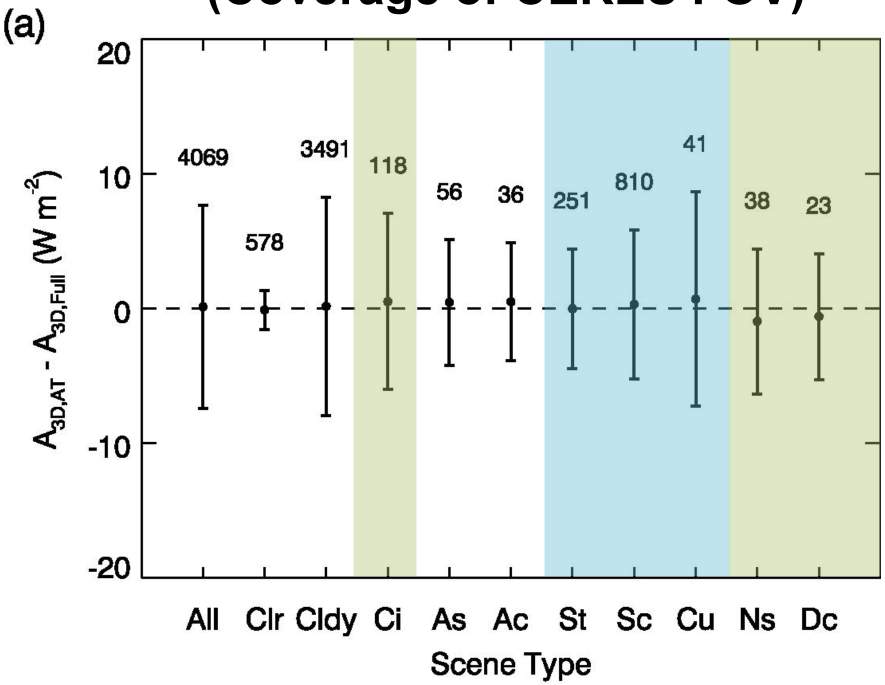
SCA versus 3D Radiation Process on Downward Surface Irradiance (Model-to-Model Difference)



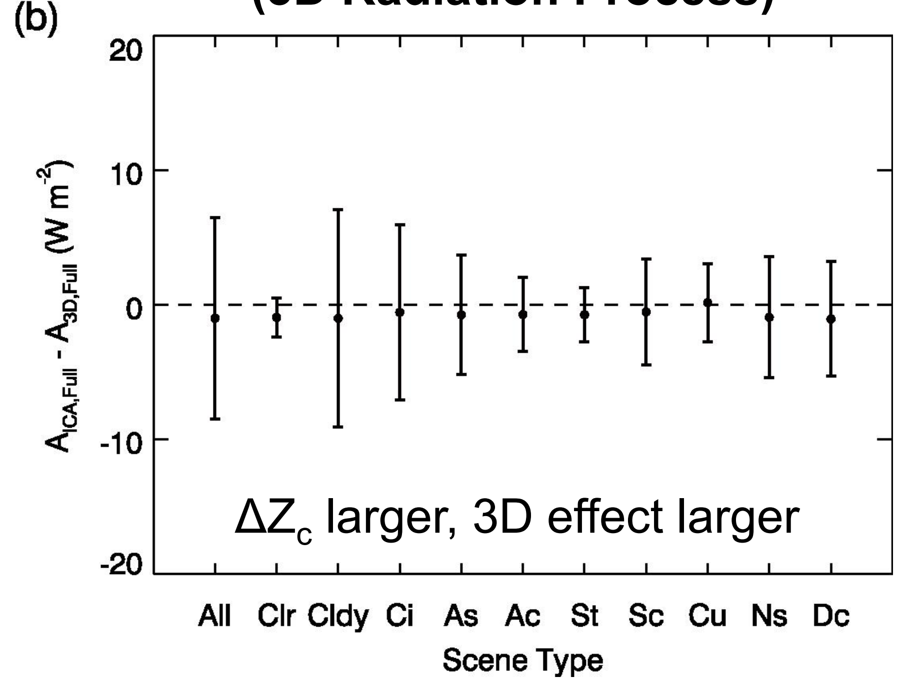
- Impact of SCA 3D atmosphere on downward surface irradiance is slightly larger than that of 3D radiative transfer.

SCA versus 3D Radiation Process on Absorbed Irradiance by Atmosphere (Model-to-Model Difference)

$A_{3D,AT} - A_{3D,Full}$
(Coverage of CERES FOV)

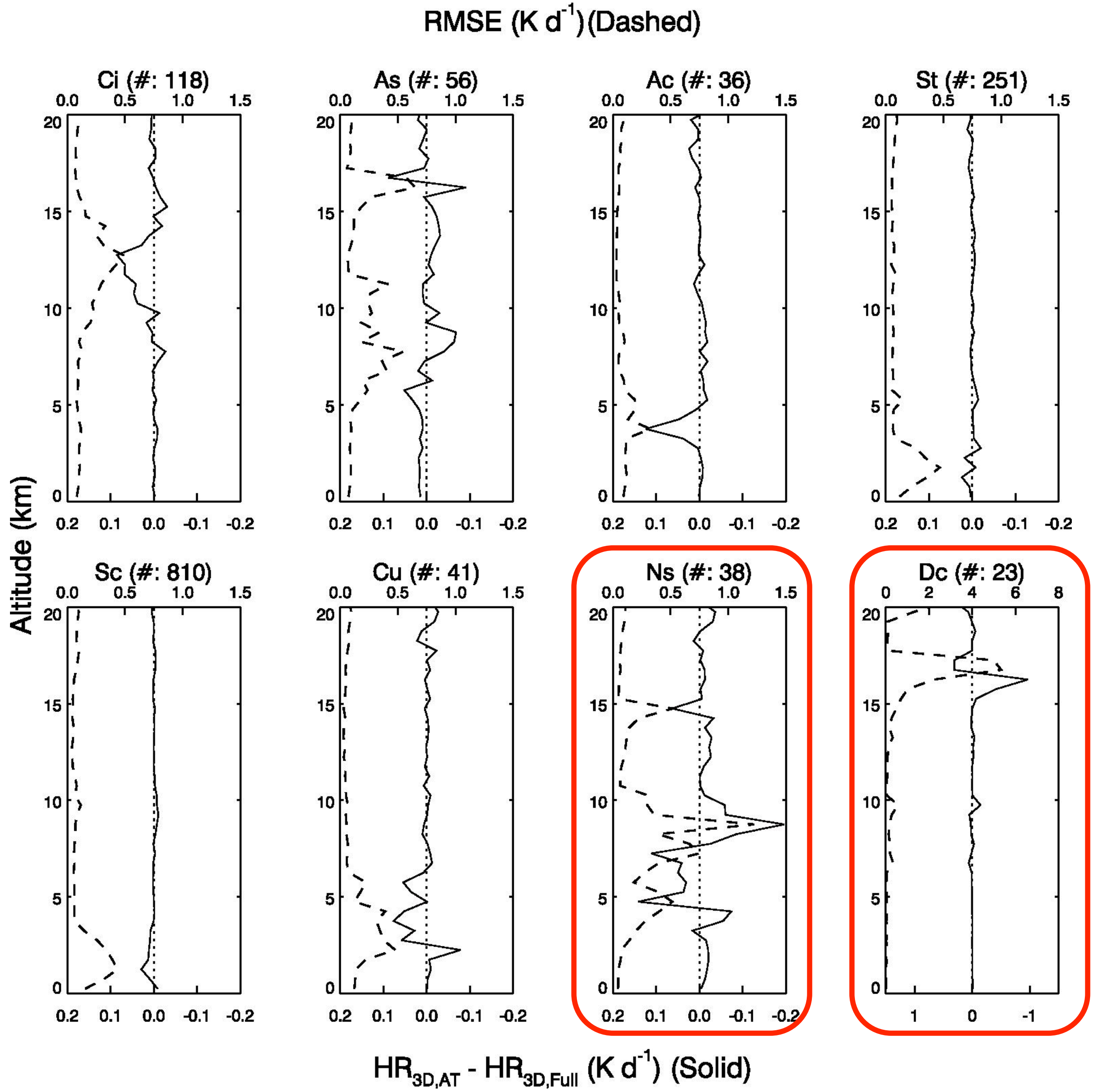


$A_{ICA,Full} - A_{3D,Full}$
(3D Radiation Process)



- Impact of SCA 3D atmosphere on atmospheric absorption is comparable to 3D radiative transfer.
- 3D cloud information improves Ns and Dc clouds significantly.

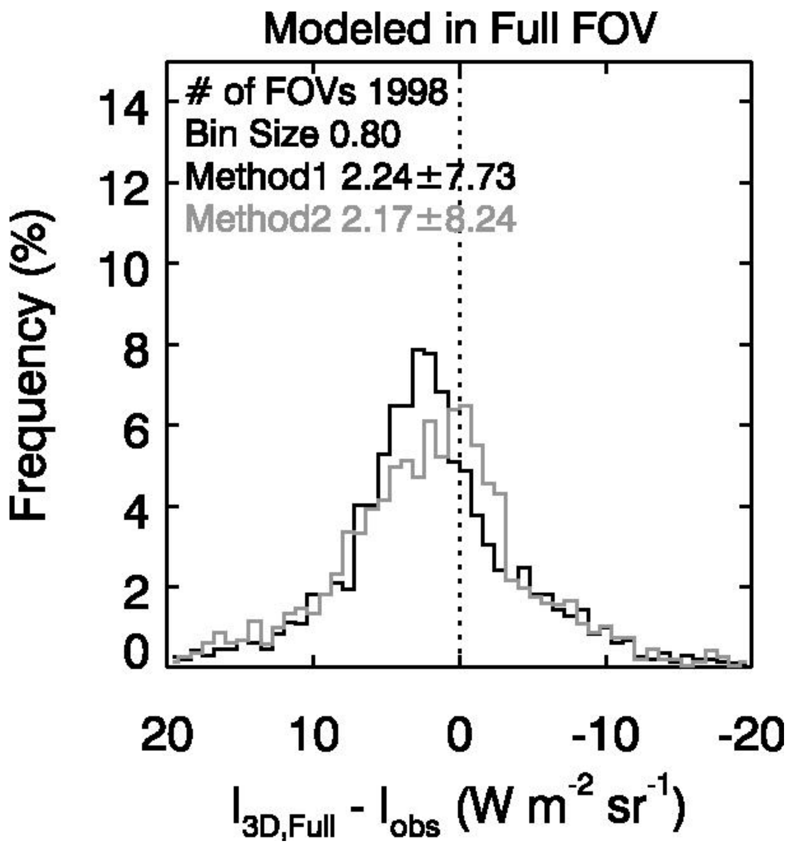
Impact of SCA on Heating Rate Profiles



Summary and Conclusions

- Scene construction algorithm (SCA) is applied to integrated 2D cloud properties from CALIPSO, CloudSat, and MODIS, generating 3D cloud atmosphere.
- SCA improves simulation accuracy of TOA radiance, showing 40% of reduction of instantaneous modeling biases.
- SCA improves simulation of TOA radiances and surface irradiance for small-scale inhomogeneous clouds such as cumulus (Cu) and stratocumulus (Sc). Homogeneous clouds such as Nimbostratus (Ns) and Deep Convective clouds (Dc) are less affected by coverage of CERES footprint.
- For case of atmospheric absorption and heating rate profiles, SCA improves simulation of Ns and Dc, because these cloud types have large amount of absorption, and are sensitive to 3D cloud information within the CERES footprint.
- Compared to 3D information (constructed by SCA), 3D radiative transfer has smaller impact on the TOA radiance. However, SCA and 3D radiation process have comparable impacts on atmospheric absorption and surface irradiance.

Modeling Accuracy Depending on Angular Correction Method



- Angular correction using CERES ADM gives smaller modeling bias but larger standard deviations.
- Angular correction either ICA model or CERES ADM gives positive modeling biases with an order of 2 W m^{-2} sr^{-1}.
- The positive modeling biases may be due to (1) uncertain input parameters such as fixed atmospheric profile and surface albedo, or (2) CERES instrumental errors as also suggested in *Hudson et al.* (2010).