CERES Science Team Meeting 2022, April 26-28th (Virtual Meeting)

Constraining CALIPSO-CloudSat-MODIS (CCM) Merged Cloud Profiles by MODIS Column Properties for CCCM Irradiance Computations

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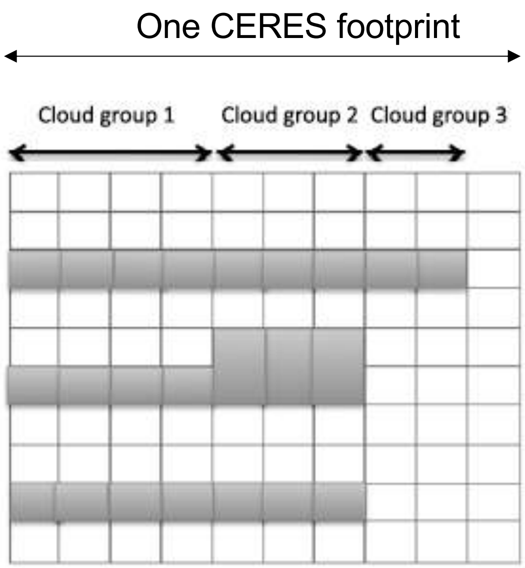
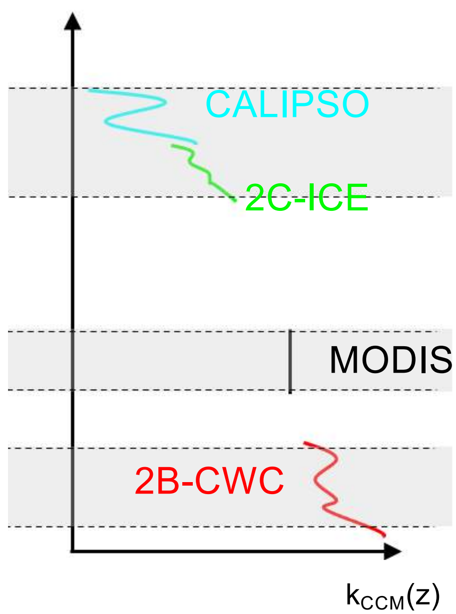
Overview of CERES-CALIPSO-CloudSat-MODIS (CCCM) CCCM Irradiance Computation Algorithm

Step 1: Merging CALIPSO-CloudSat (CC) cloud mask at a CALIPSO resolution (1/3 km) and generating CC cloud groups in a CERES footprint

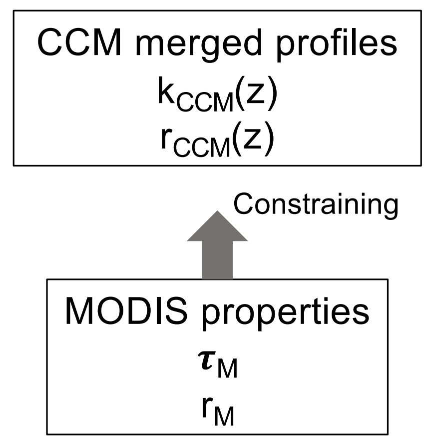


(Kato et al. 2010)

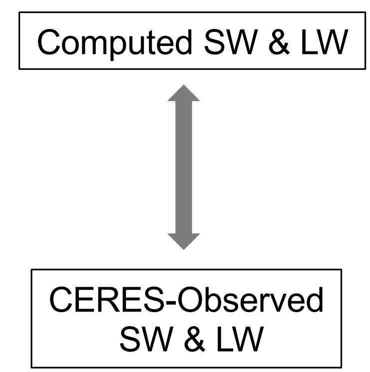
Step 2: Generating CALIPSO-CloudSat-MODIS (CCM)-merged $k_{CCM}(z)$ and $r_{CCM}(z)$ profiles by brining available product based on the predefined hierarchy



Step 3: Constraining CCM-merged $k_{CCM}(z)$ and $r_{CCM}(z)$ by MODIS column properties (τ_M, r_M)



Step 4: Running Fu-Liou radiative transfer model and comparing computed irradiances with CERES observations



(Kato et al. 2011; Ham et al. 2022)

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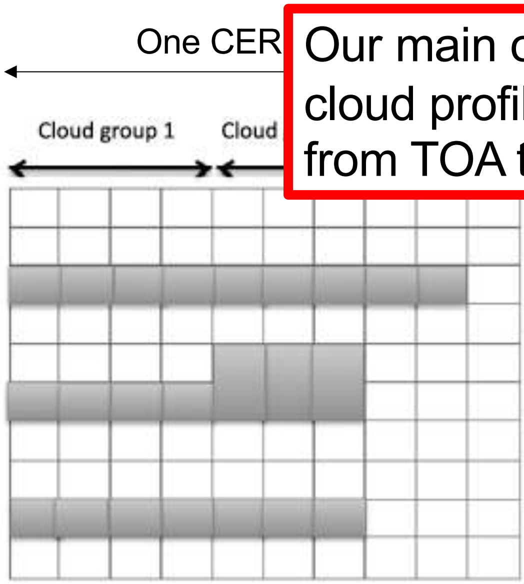
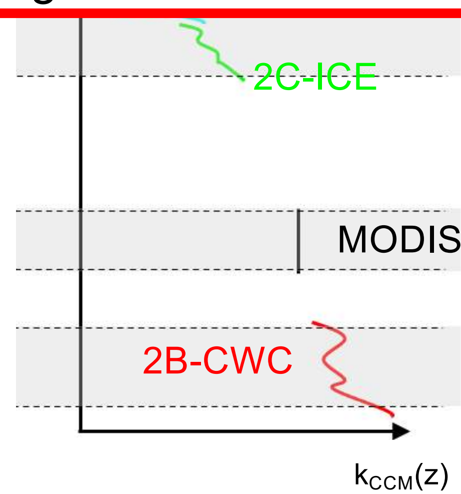
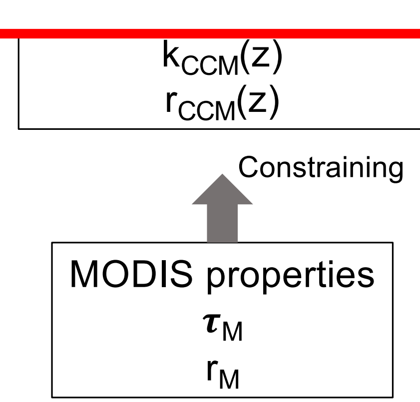
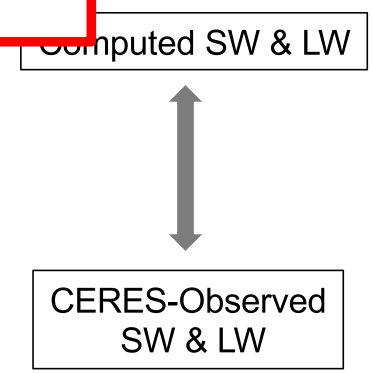
Our main objective is to generate more realistic and accurate cloud profiles from multi-sensors for irradiance computations from TOA through surface.



(Kato et al. 2010)





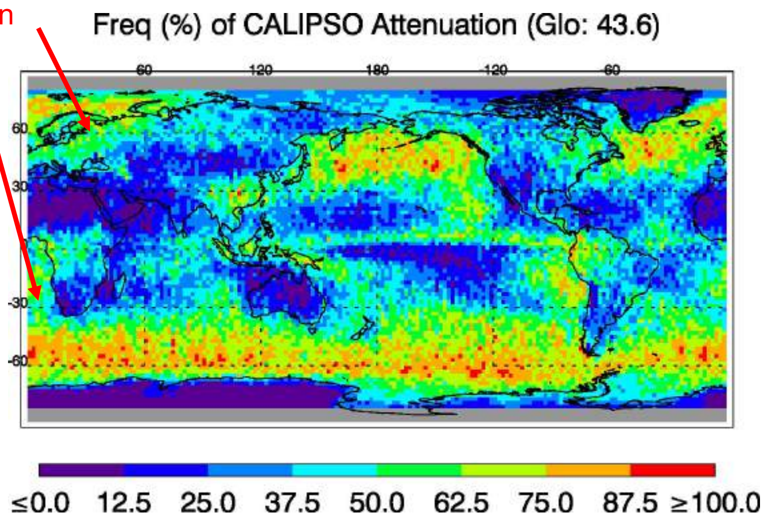


(Kato et al. 2011; Ham et al. 2022)

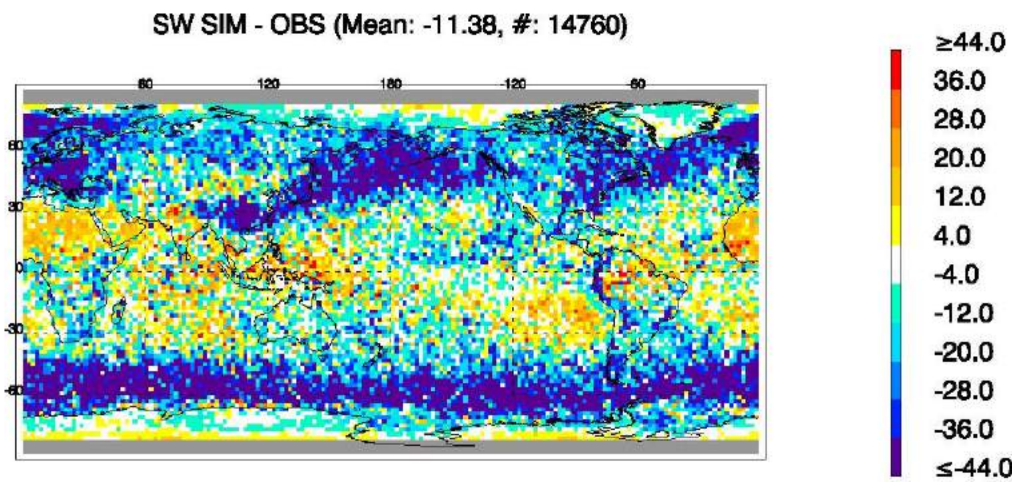
Necessity of The Constraining Method: Biases When TOA SW Fluxes Is Computed Without Step 3

Jan/Apr/Jul/Oct 2008

The regions where CALIPSO attenuation occurs



TOA SW Bias to CERES Observation



- Large SW negative biases occur in the high-latitude regions where 1) CALIPSO signal is fully attenuated, and 2) low clouds < 1km are present. This indicates bottom parts of low clouds are missed by CloudSat and CALIPSO, causing negative SW biases.
- CALIPSO profiles have larger noise near the attenuation level.
- Noises due to differences across the satellite product.

➔ These uncertainties can be reduced if we use additional information of MODIS column cloud properties.

Visible Scaled Cloud Optical Depth (VSCOD) Constraining Method

- While CALIPSO and CloudSat active sensors provide detailed cloud vertical profiles, these do not often see the entire cloud column. In contrast, MODIS passive sensor provides more reliable cloud column-integrated values.
- Therefore, we take the shape of merged cloud vertical profiles (k_{CCM}, r_{CCM}), while the merged cloud profiles are normalized/constrained by MODIS cloud column-cloud (τ_M and r_M) properties.

- The scaling factor to $k_{CCM}(z)$ is derived to have a consistent VSCOD with MODIS (Kato et al., 2011)

$$\tau_M\left(1 - g(r_M)\right) = \alpha \sum_{i=1}^{n} k_{CCM}(i)\Delta z_i \left\{1 - g\left(r_{CCM}(i)\right)\right\}$$

MODIS Scaled Cloud Optical Depth

α is a scaling factor to reproduce MODIS-equivalent scaled optical depth from the merged extinction profile ($\alpha\ k_{CCM}(i)$).

- Note that visible channel (non-absorbing) radiance is a function of VSCOD (Van de Hulst 1974), and thus the use of MODIS VSCOD reproduces MODIS visible channel radiances. By constraining $k_{CCM}(z)$ with MODIS VSCOD, the scaled $\alpha\ k_{CCM}(z)$ would reproduce MODIS-equivalent visible channel radiances too.
- Since SW broadband and visible channel radiances are correlated well, this method also guarantees close agreement with SW TOA broadband observations.

No Constraining (without Step 3) vs VSCOD Constraining Method

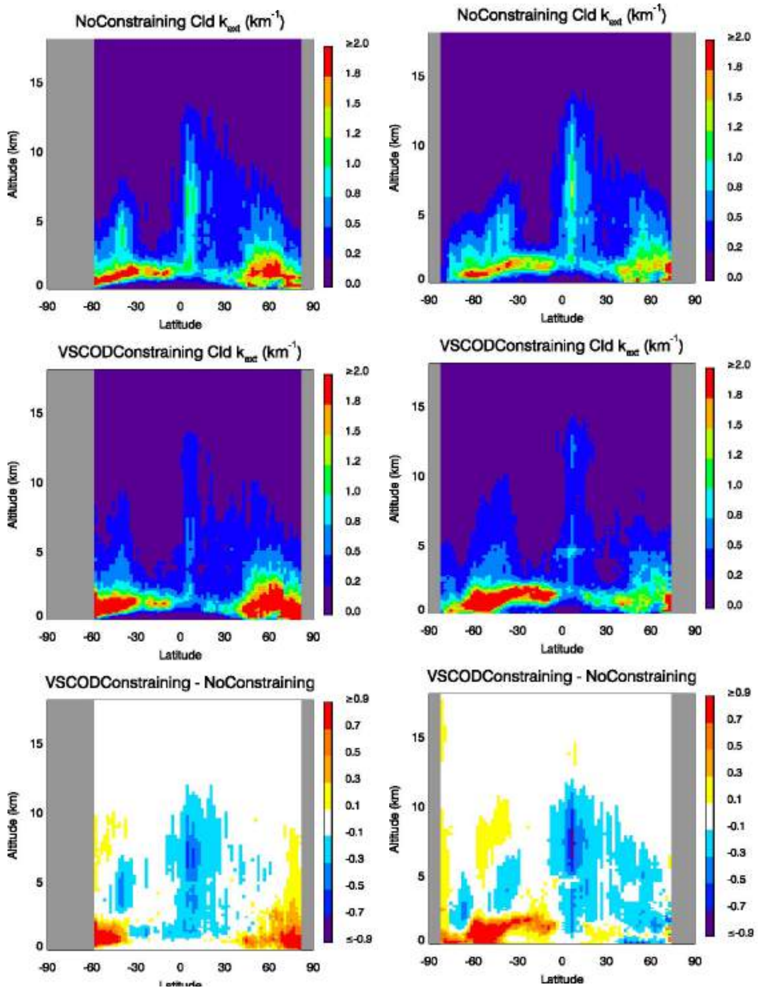
July 2008

SZA < 82°   SZA ≥ 82°

$k_{CCM}(z)$

$\alpha k_{CCM}(z)$
where α is derived from VSCOD method

$\alpha k_{CCM}(z) - k_{CCM}(z)$



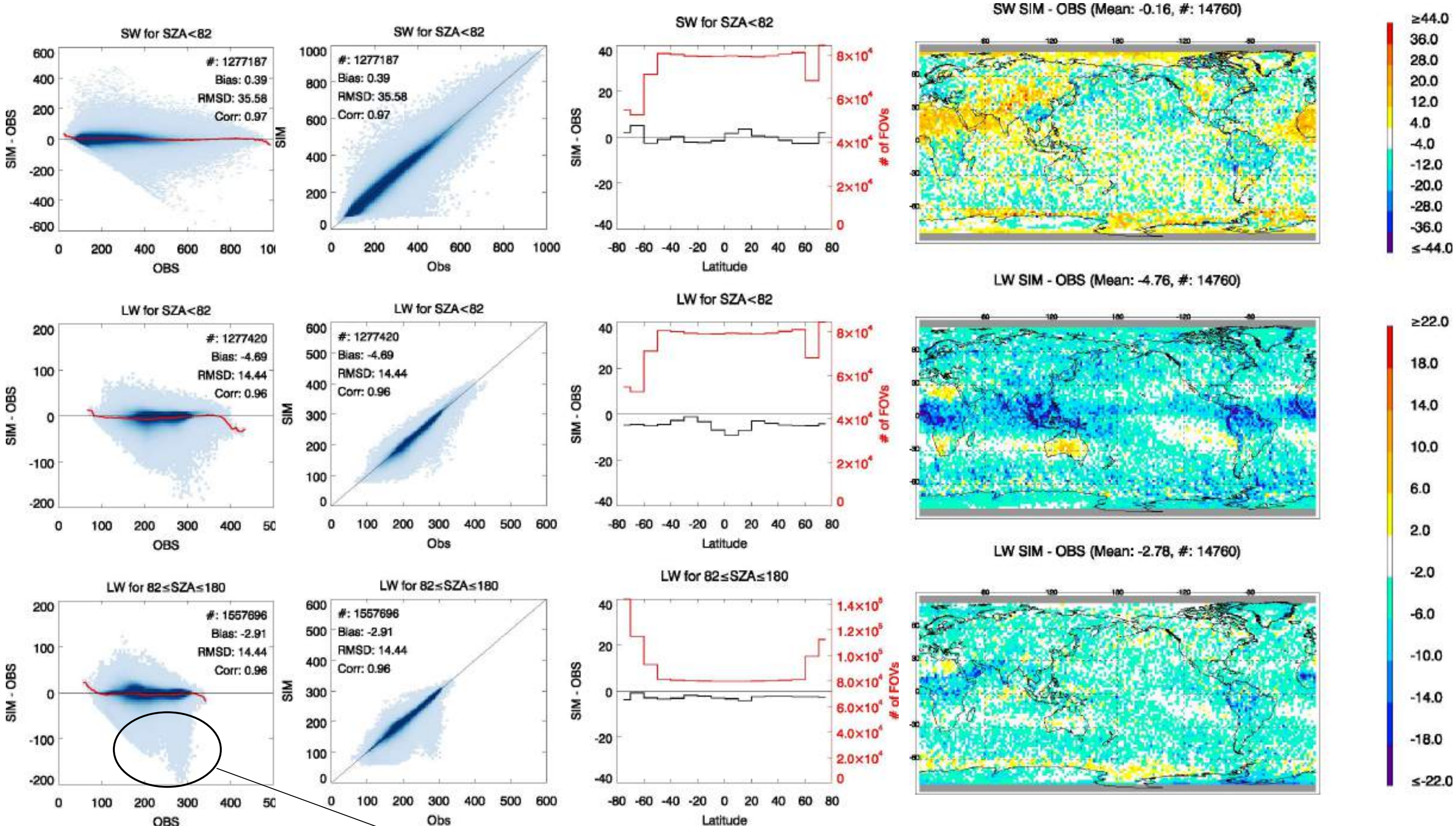
- $k_{CCM}(z)$ in low clouds in high-latitude regions is increased by VSCOD constraining method.
- $k_{CCM}(z)$ over the tropical regions is generally reduced by VSCOD method. This may imply the overestimation of cloud extinction coefficient used for the ice phase (CALIPSO or 2C-ICE).

SW and LW Biases ($W\ m^{-2}$) to CERES Obs When VSCOD Constraining Method is used for $\alpha k_{CCM}(z)$

Daytime SW

Daytime LW

Nighttime LW



VSCOD method produces SW TOA irradiances close to CERES observations.

Negative LW biases indicate too high radiative center of $k_{CCM}(z)$ profiles: 1) overestimated $k_{ext}(z)$ used for upper clouds in merging process. 2) Missed cloud bottom parts are compensated by the increased α scaling factor.

VSCOD method generally works well but nighttime LW biases are sometimes large negative in instantaneous footprint scales.

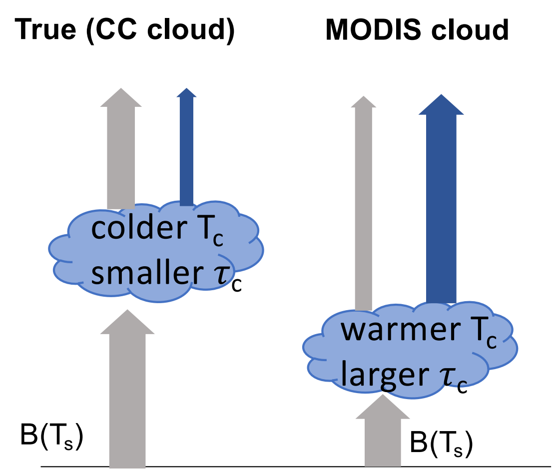
Jan/Apr/Jul/Oct 2008

Coupled MODIS T_c and τ_c Biases in MODIS IR (Nighttime) Retrievals

Nighttime MODIS τ_c is derived from MODIS IR channel, which is affected by the cloud height (or T_c). If MODIS cloud height is low-biased (or warm-biased T_c), MODIS τ_c would be positively biased.

$$R_{IR,MODIS} \sim \varepsilon_s B(T_s)\exp(-\tau_c) + B(T_c)(1-\exp(-\tau_c))$$

Warm biased   Positively biased

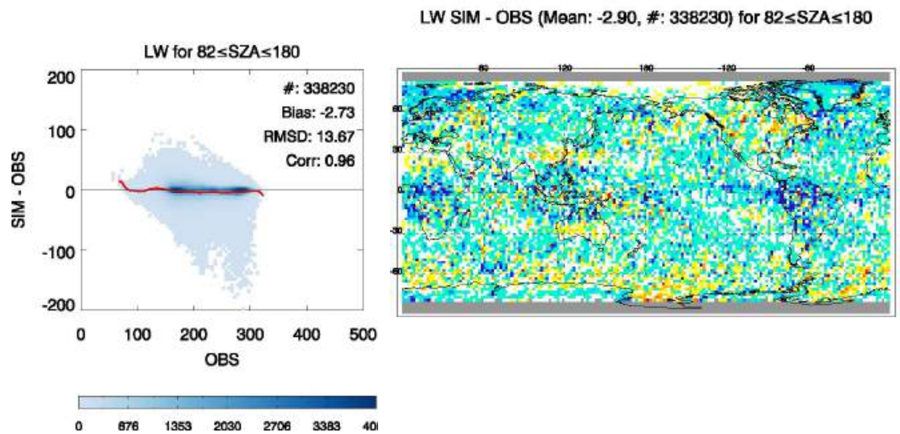


Both clouds reproduce TOA IR radiances close to MODIS IR observations.

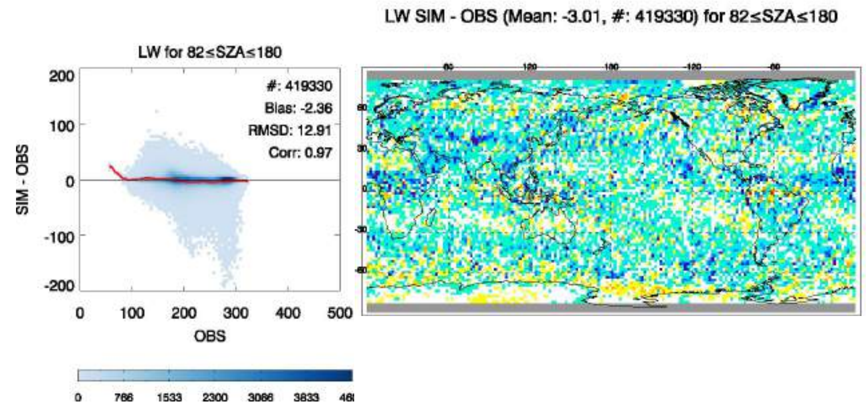
When the biased MODIS τ_c is used for VSCOD method, the bias also affects $\alpha k_{CCM}(z)$. The negative LW biases indicate that $\alpha k_{CCM}(z)$ might be overestimated due to the overestimated MODIS τ_c (& warm-biased T_c)

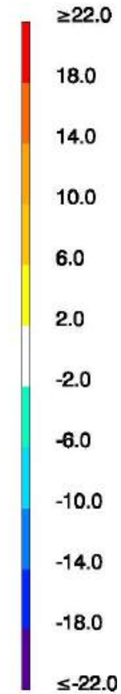
Which Month Shows Large Negative Nighttime LW Biases (likely from warm-biased MODIS T_c and positively biased MODIS τ_c) When VSCOD Method Is Used?

Jan 2008

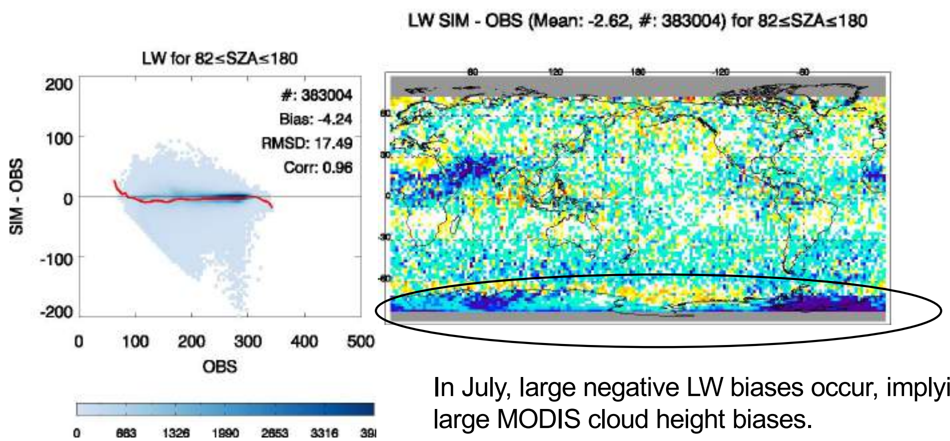


April 2008



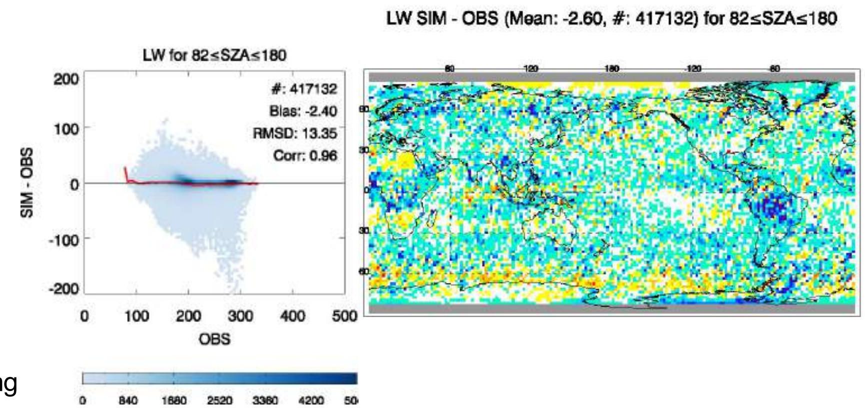


July 2008

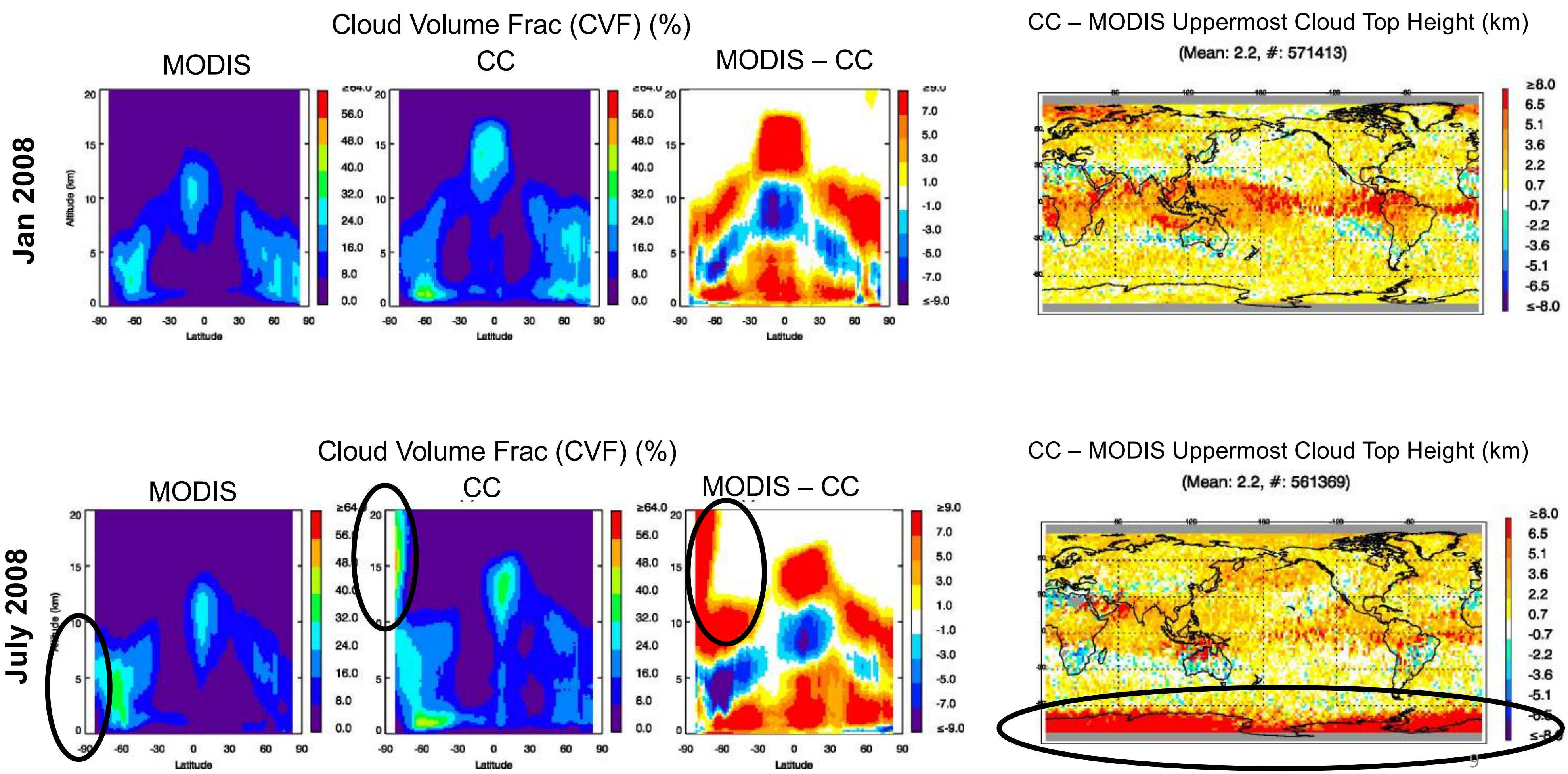


In July, large negative LW biases occur, implying large MODIS cloud height biases.

October 2008



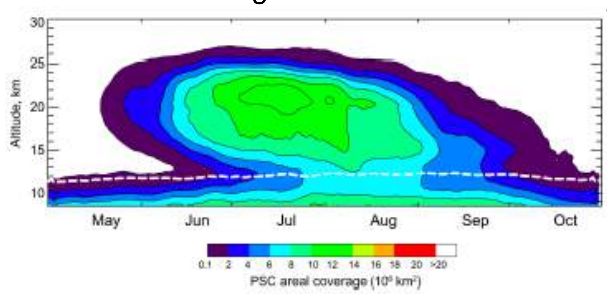
Large Cloud Height Differences between MODIS and CC over Antarctica During Wintertime



Polar Stratospheric Cloud Type II (Consisting of Ice Particles) Missed in MODIS IR Cloud Retrievals

- Type II PSC is prevalent over the Antarctica during wintertime (June – Sep) (Noel et al. 2008; Pitt 2018). MODIS often detects this type of clouds as low/mid clouds below the tropopause (~ 11 km).

PSC areal coverage over the Antarctic



Tropopause (~ 11km)

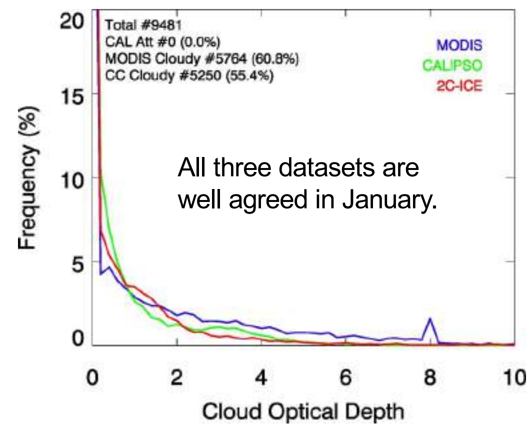
Figure 14. Twelve-year mean daily PSC areal coverage over the Antarctic. The climatological daily maximum MERRA-2 tropopause height is indicated by the dashed white line.

(Pitt et al. 2018)

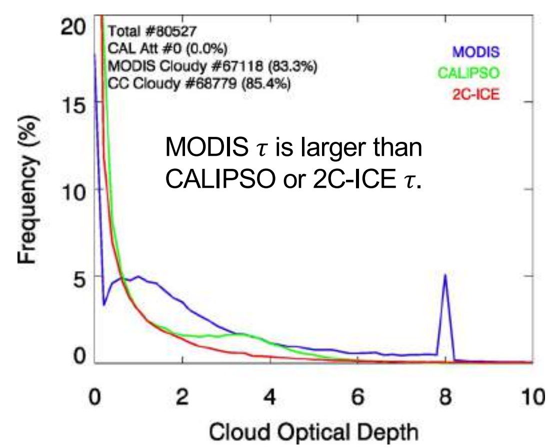
Nighttime τ distributions for the CERES footprints with no CALIPSO attenuation over Antarctica

MODIS
CALIPSO
2C-ICE

January 2008



July 2008



IR Emission (IREMIS) Constraining Method

- Even though each term of MODIS $\boldsymbol{\tau}_c$ and T_c is biased in IR retrievals, these two parameters would be able to reproduce MODIS IR channel radiances by the algorithm design.
- Therefore, instead of using MODIS $\boldsymbol{\tau}_c$ (or VSCOD=(1–g)$\boldsymbol{\tau}_c$) for constraining k_{CCM}, we can use both terms (MODIS $\boldsymbol{\tau}_c$ and T_c) to obtain IR emission, which can be further used for constraining merged k_{CCM}.
- We use 11 μm for computing IR emission term.

MODIS-estimated IR emission

α is a scaling factor to reproduce MODIS-equivalent IR emission from the merged extinction profile (α k_{CCM}(i)).

$$IREMIS\left(T_{c,M},\tau_M\right) = IREMIS(\alpha k_{CCM}(z), r_{CCM}(z))$$

Approximately, IREMIS for a single cloud layer is

$$\varepsilon_s B(T_s)\exp(-\tau_M) + B(T_{c,M})(1-\exp(-\tau_M))$$

Limitations of the IREMIS Method

- If cloud temperature is too close to surface temperature, the IR emission value become nearly constant regardless of the scaling factor, and the uncertainty of the scaling factor gets larger. In this case, the uncertainty of surface temperature and temperature profile also significantly change the scaling factor.
- In addition, the sensitivity of IR emission gets quickly reduced as COD increases, meaning that retrieval of accurate α factor is not possible for optically thick clouds.

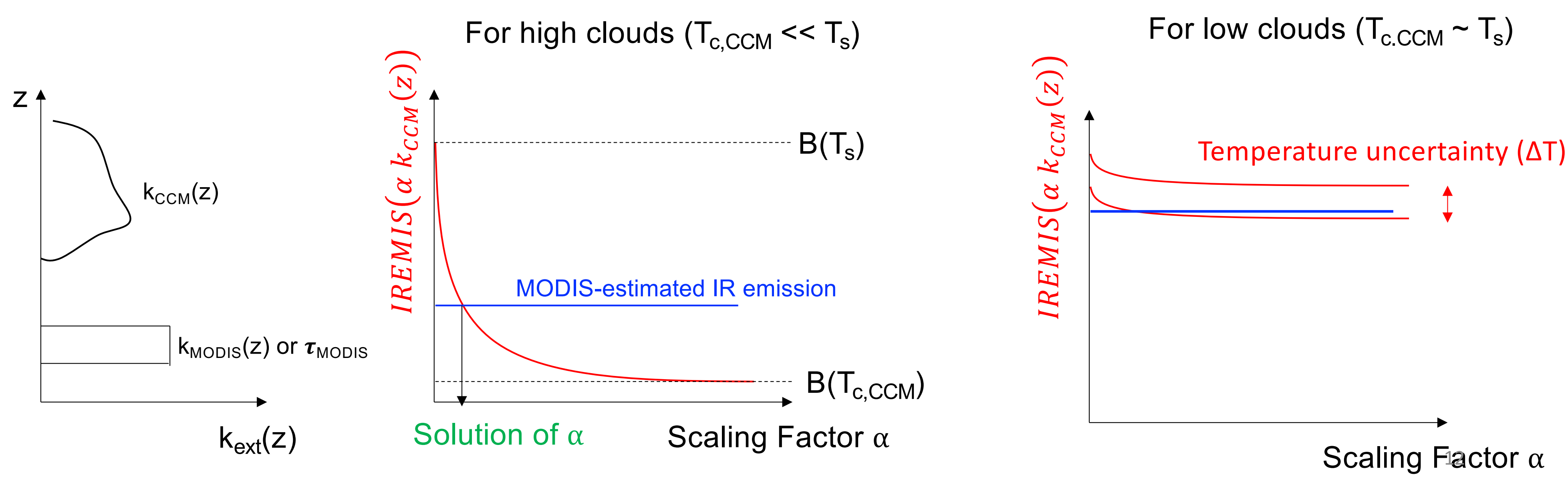
Approximately

$\varepsilon_s B(T_s)\exp(-\tau_M) + B(T_{c,M})(1 - \exp(-\tau_M))$

$$IREMIS(T_{c,M}, \tau_M) = IREMIS(\alpha\, k_{CCM}(z), r_{CCM}(z))$$

MODIS-estimated IR emission

CCM-estimated IR emission with changing α

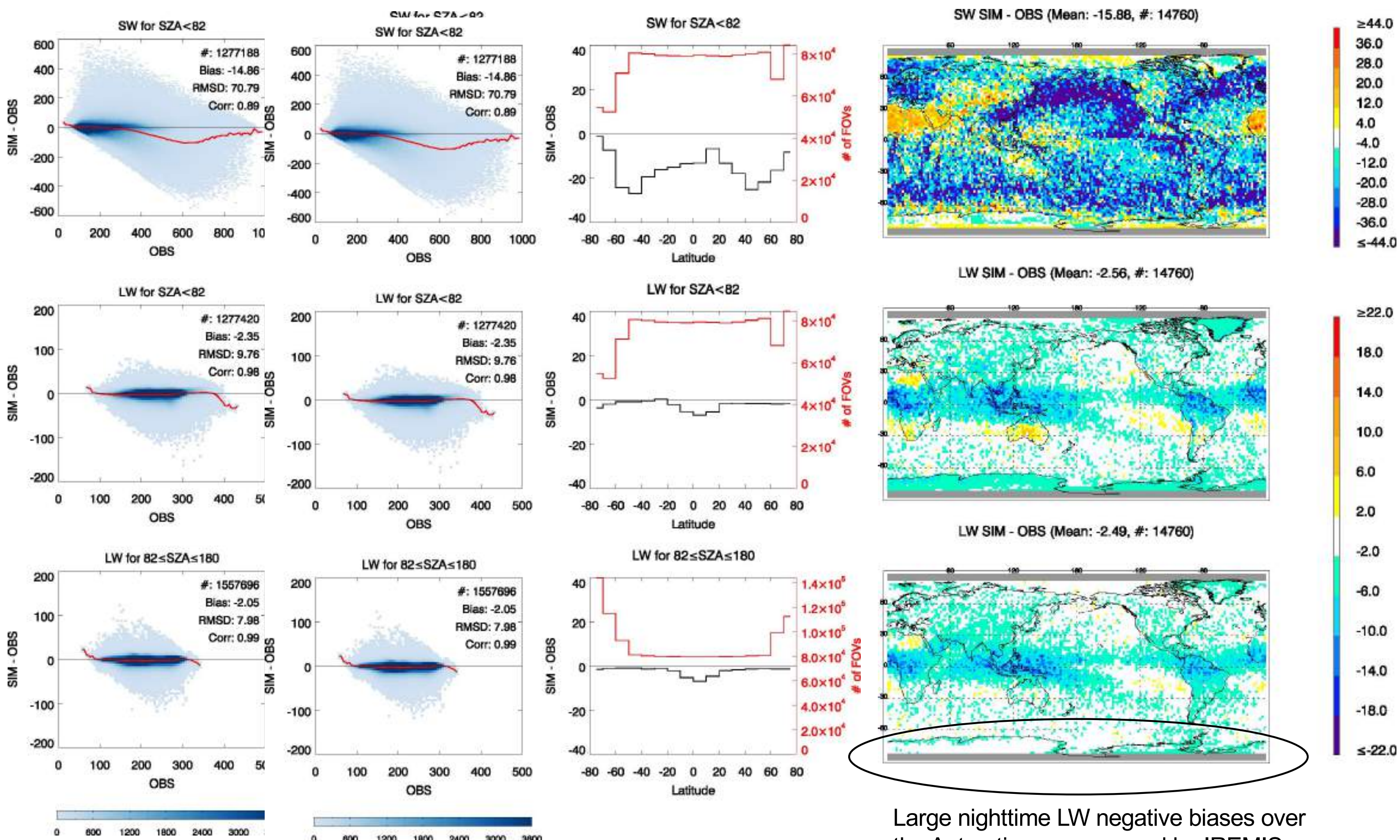


SW and LW Biases (W m^{-2}) to CERES Obs when IREMIS Constraining Method is used for $\alpha k_{CCM}(z)$

Daytime SW

Daytime LW

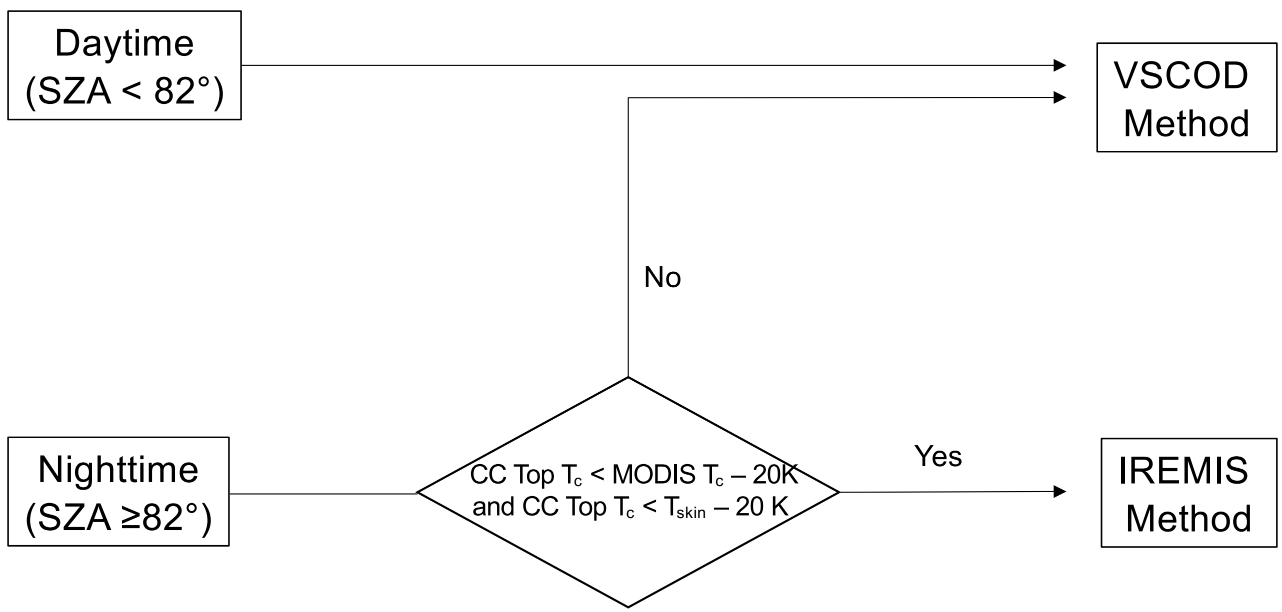
Nighttime LW



Large negative SW biases for Low cloud regions due to the limitation of IREMIS method.

Large nighttime LW negative biases over the Antarctica are removed by IREMIS method.

Hybrid Approach



In this approach, VSCOD method is mostly used. However, if MODIS Tc is different from CC Tc (that indicates MODIS Tc bias), and CC Tc is distinctive from skin temperature, IREMIS method is applied.

TOA SW and LW Biases to CERES Observations

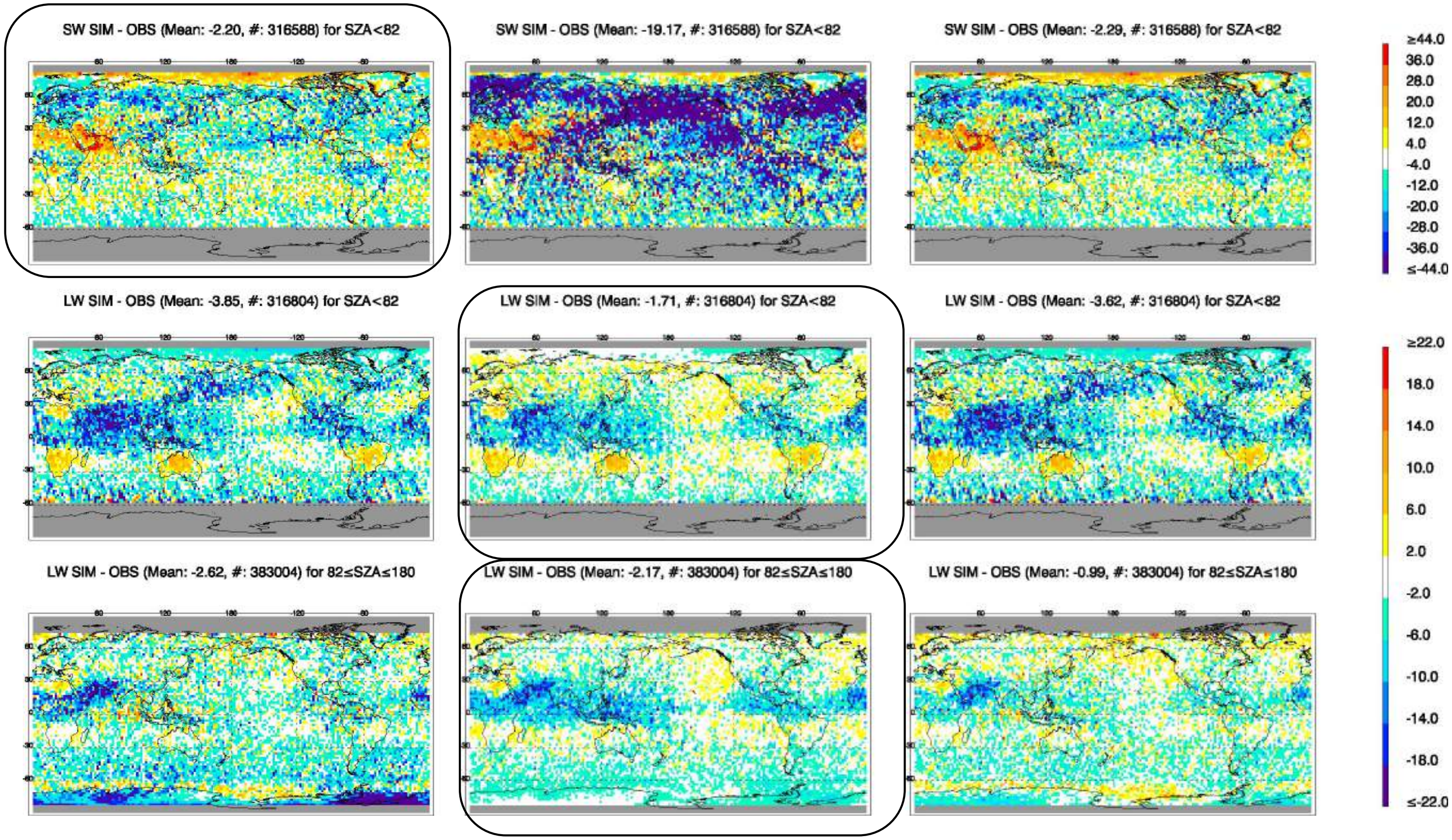
200807

VSCOD IREMIS Hybrid

SW

LW Day

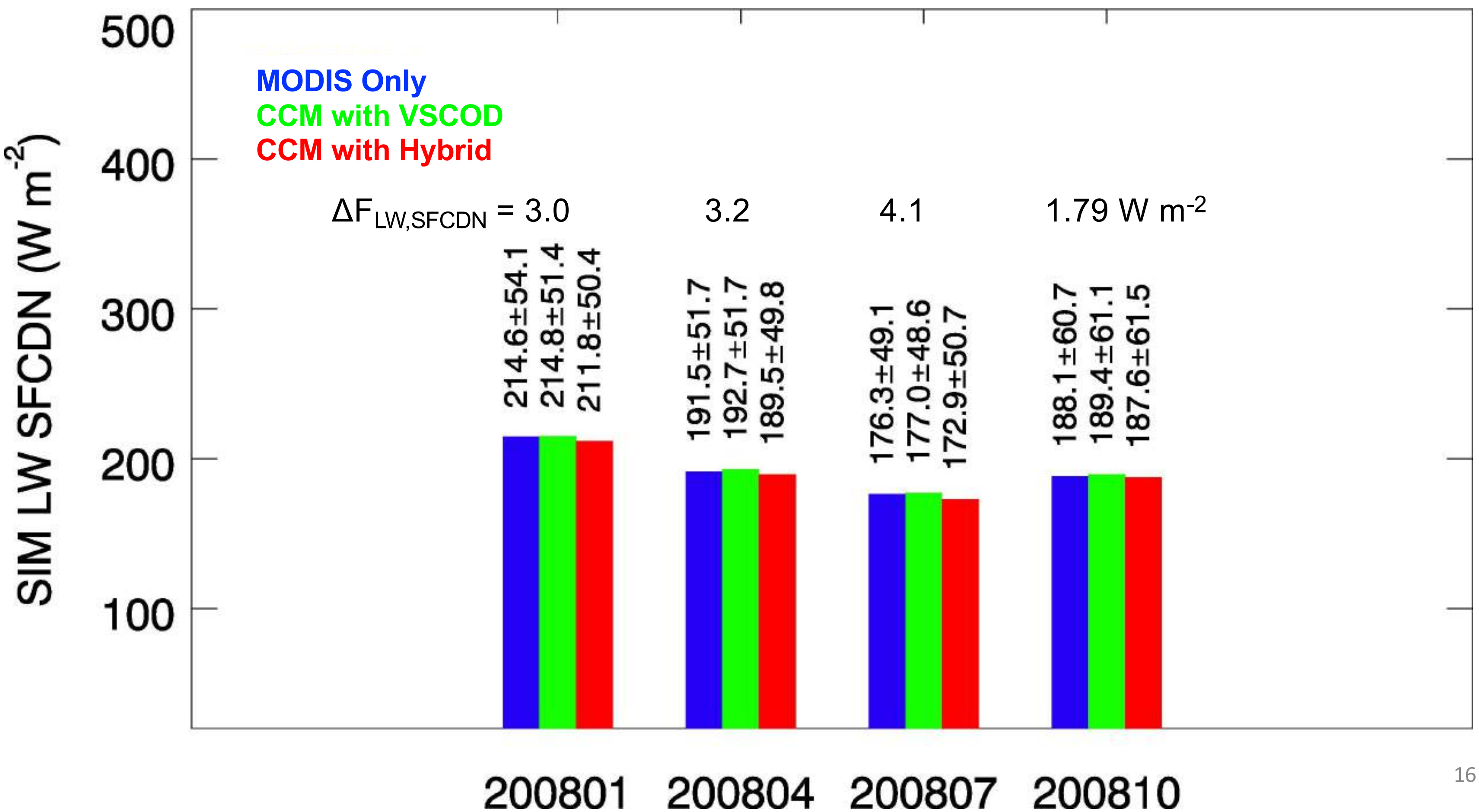
LW Night



When combining VSCOD and IREMIS, SW and LW biases are reduced.

MODIS Only from CRS-like

Day+Night LW Surface Downward (W m^{-2}) over Antarctica



Summary

- VSCOD method is shown to improve SW simulations by increasing $\alpha k_{CCM}(z)$ in case that both CALIPSO and CloudSat miss low clouds. However, the VSCOD method sometimes induces nighttime negative LW biases when MODIS cloud height is low-biased.
- IREMIS method is shown to improve nighttime LW simulation especially for PSC over the Antarctica. However, IREMIS method does not work well for low clouds when the cloud temperature is too close to surface temperature, or for optically thick clouds.
- A hybrid method is considered by combining VSCOD and IREMIS methods.
- By implementing the hybrid method, wintertime surface LW downward is reduced by 4 W m^{-2} over the Antarctic, compared to VSCOD scaling method.

Thank you for your attention!