CERES Angular Distribution Model Working Group Report

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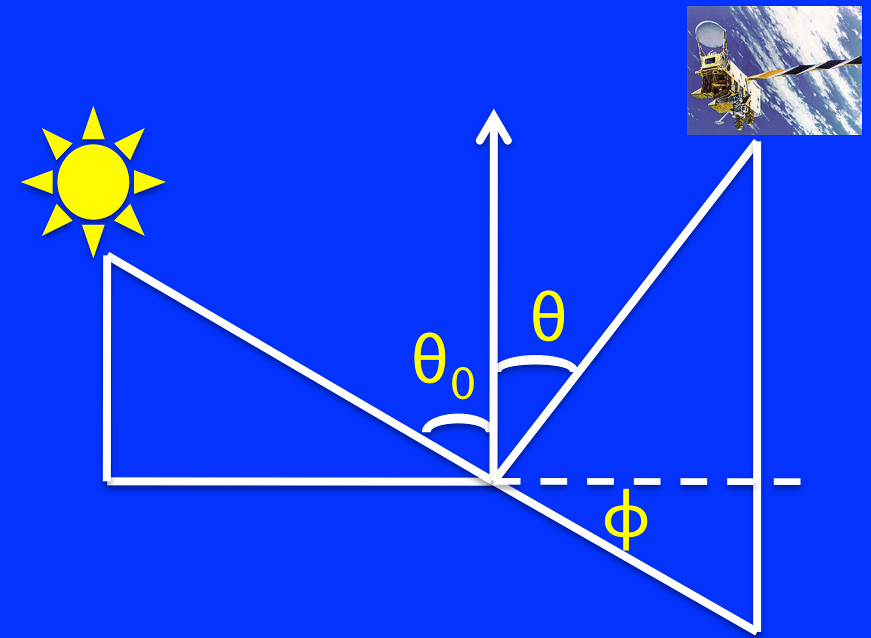
Publications

- Wenying Su, Norman Loeb, Lusheng Liang, Nana Liu, Chuntao Liu, The El Nino-Southern Oscillation Effect on Tropical Outgoing Longwave Radiation: A Daytime Versus Nighttime Perspective, JGR, 2017, DOI: 10.1002/2017JD027002.
- Zachary Eitzen, Wenying Su, Kuan-Man Xu, Norman Loeb, Moguo Sun, David Doelling, Fred Rose, and Alejandro Bodas-Salcedo, Evaluation of a general circulation model by the CERES Flux-by-Cloud Type simulator, JGR. 2017, accepted.
- Wenying Su, Lusheng Liang, Walter Miller, and Victor Sothcott, The effects of different footprint sizes and cloud algorithms on the top-of-atmosphere radiative flux calculation from CERES instrument on Suomi-NPP, Atmos. meas. tech., amt-2017-75, 2017, accepted.

From radiance to flux: angular distribution models

- Sort observed radiances into angular bins over different scene types;
- Integrate radiance over all θ and ϕ to estimate the anisotropic factor for each scene type;
- Apply anisotropic factor to observed radiance to derive TOA flux;



$$R(\theta_0, \theta, \phi) = \frac{\pi \hat{I}(\theta_0, \theta, \phi)}{\int_0^{2\pi} \int_0^{\frac{\pi}{2}} \hat{I}(\theta_0, \theta, \phi) cos\theta sin\theta d\theta d\phi} = \frac{\pi \hat{I}(\theta_0, \theta, \phi)}{\hat{F}(\theta_0)}$$

$$F(\theta_0) = \frac{\pi I_o(\theta_0, \theta, \phi)}{R(\theta_0, \theta, \phi)}$$

Predicted radiance vs. observed radiance

$$R(\theta_0, \theta, \phi) = \frac{\pi \hat{I}(\theta_0, \theta, \phi)}{\hat{F}(\theta_0)} \qquad F(\theta_0) = \frac{\pi I_o(\theta_0, \theta, \phi)}{R(\theta_0, \theta, \phi)}$$

$$F(\theta_0) = \frac{I_o(\theta_0, \theta, \phi)}{\hat{I}(\theta_0, \theta, \phi)} \hat{F}(\theta_0)$$

- Predicted radiances can be used to verify the accuracy of ADM;

Normalize predicted and observed radiance

Observed radiance:

$$I_j^o, \quad j = 1, \cdots, n$$

Predicted radiance:

$$\hat{I}_j, \quad j = 1, \cdots, n$$

1°

1°

$$\overline{I^o} = \frac{1}{n}\sum_{j=1}^{n} I_j^o \qquad \overline{\hat{I}} = \frac{1}{n}\sum_{j=1}^{n} \hat{I}_j$$

$$RMS = \sqrt{\frac{1}{n}\sum_{j=1}^{n}\left(\frac{\hat{I}_j}{\overline{\hat{I}}} - \frac{I_j^o}{\overline{I^o}}\right)^2}$$

- RMS error between normalized predicted radiance and normalized observed radiance is closely related to the ADM error

Is normalized radiance RMS error a good metric

- Simulate a radiance and flux database over different scene types, for a set of Sun-viewing geometries;
- Assuming the simulated radiances (I^s) and fluxes (F^s) are the truth;
- For each simulated radiance, there is a corresponding predicted radiance from CERES ADMs; and the CERES ADMs are used to convert the simulated radiances to fluxes;
- The RMS error between normalized predicted radiances and normalized simulated radiances can be calculated as follows:

$$RMS = \sqrt{\frac{1}{n}\sum_{j=1}^{n}\left(\frac{\hat{I}_j}{\overline{\hat{I}}} - \frac{I_j^s}{\overline{I^s}}\right)^2}$$

- The relative flux RMS error between simulated flux and ADMs inverted flux are calculated as:

$$\phi = \frac{\sqrt{\frac{1}{n}\sum_{j=1}^{n}\left(F_j - F_j^s\right)^2}}{\frac{1}{n}\sum_{j=1}^{n}F_j^s}$$

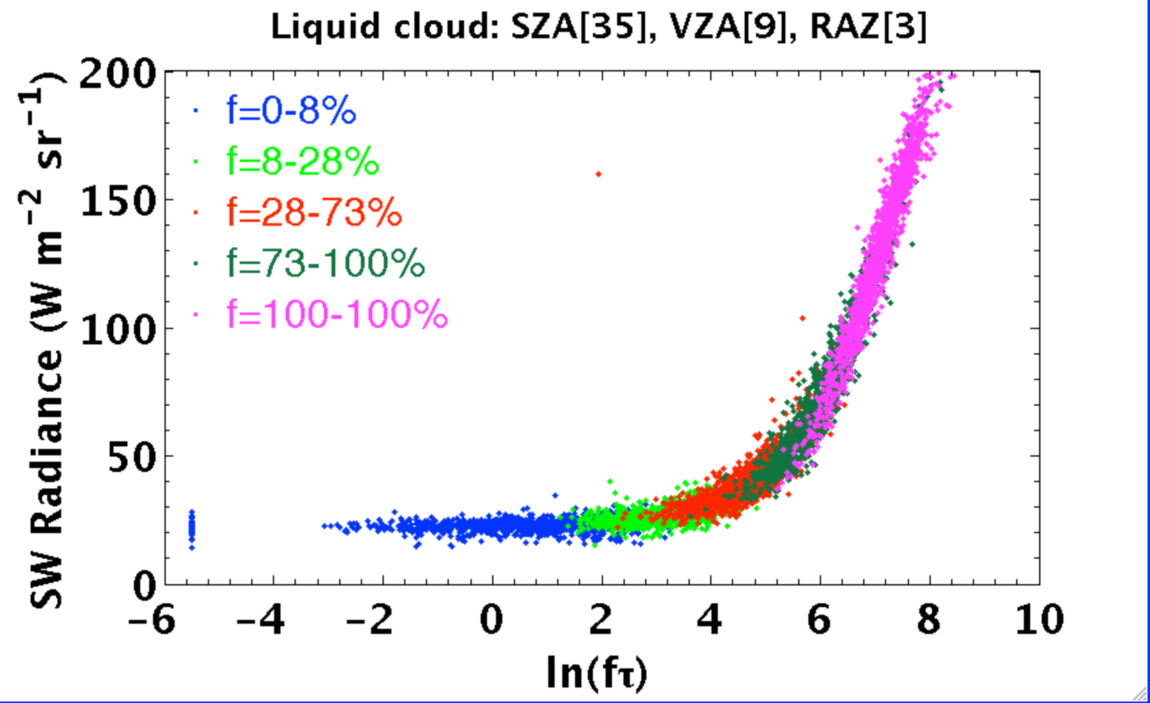
Simulation over cloudy ocean

- Radiances and fluxes are calculated for solar zenith angles of 41.4 and 60.0 degrees over cloudy ocean for the following conditions:
  - Liquid cloud optical properties provided by Ping Yang's group, effective radius of 4, 10, 16, and 25 μm are included;
  - Single-habit ice cloud optical properties provided by Ping Yang's group, effective diameter of 21, 46, and 115 μm are included;
  - Cloud optical depths : 1, 2, 4, 12, 14, 20, 217;
  - Viewing zenith angles: 0 to 88 with a bin width of 4
  - Relative azimuth angles: 0 to 180 with a bin width of 10
  - Ocean wind speed: 9m/s
  - US standard atmospheric profiles

Angular distribution model over cloudy ocean

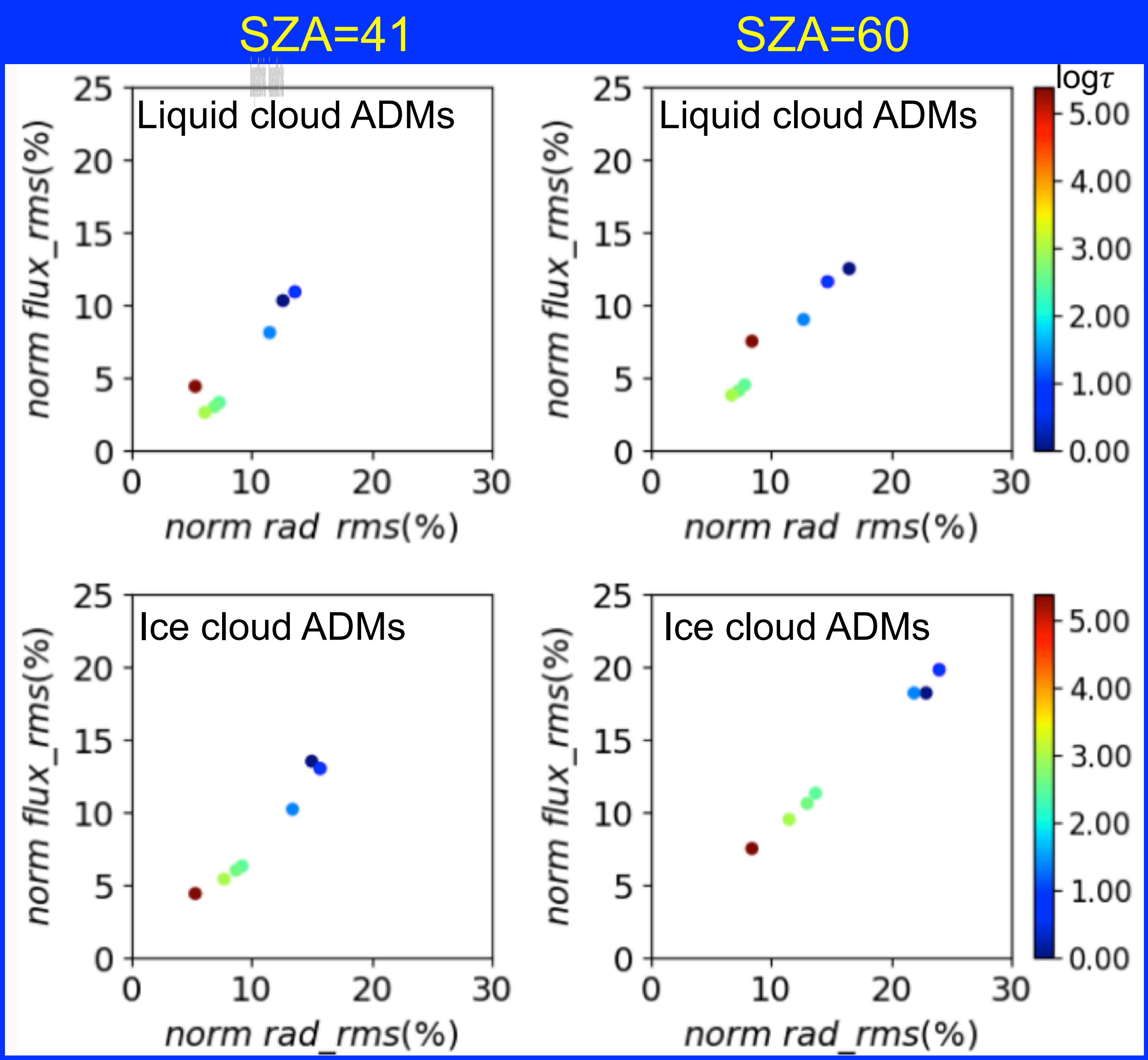
- For glint angle > 20°, or glint angle < 20° and ln(fτ) > 6:
  - For a given $[\theta_0, \theta, \varphi,]$ bin, average instantaneous radiances into 775 intervals of ln(fτ), separately for liquid, mixed, and ice clouds;
  - Apply a five-parameter sigmoidal fit to mean radiance and ln(fτ);

$$I = I_0 + \frac{a}{[1 + e^{-(x-x_0)/b}]^c}$$



Normalized radiance RMS errors and relative flux RMS errors for simulated liquid clouds

- There is a strong relationship between normalized radiance RMS error and the relative flux RMS error;
- Applying ice cloud ADMs for liquid clouds increases both the normalized radiance RMS error and the relative flux RMS error.



Normalized radiance RMS errors and relative flux RMS errors for simulated ice clouds

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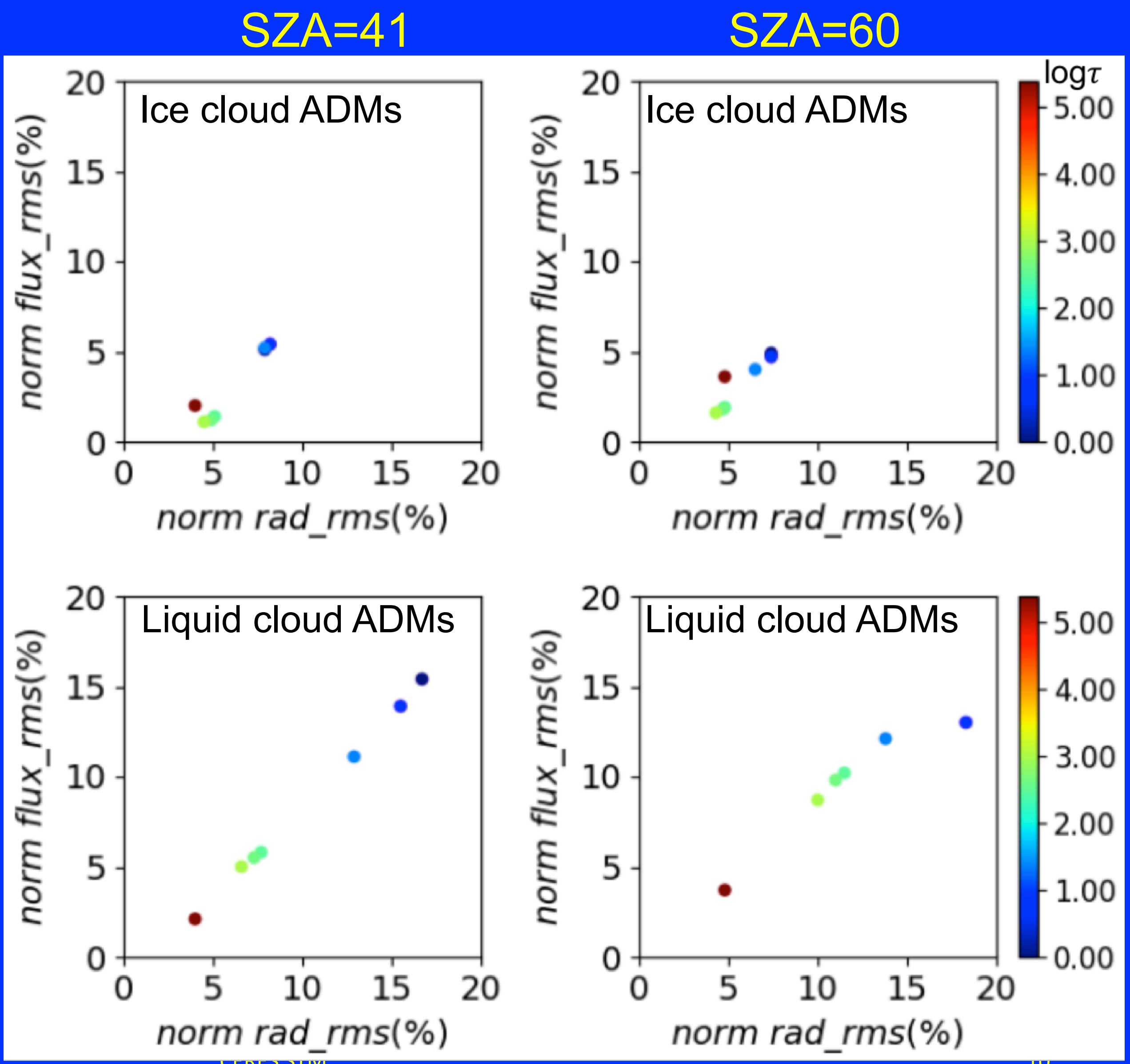


Do we need to consider other variables in cloudy ocean ADMs?

- Current ADMs consider cloud optical depth, cloud fraction, and cloud phase;
- Can we further improve the ADMs by accounting for cloud inhomogeneity using standard deviation of cloud optical depth;
- For each solar zenith angular bin, determine the terciles of standard deviation of cloud optical depth, and develop ADMs for each of them.

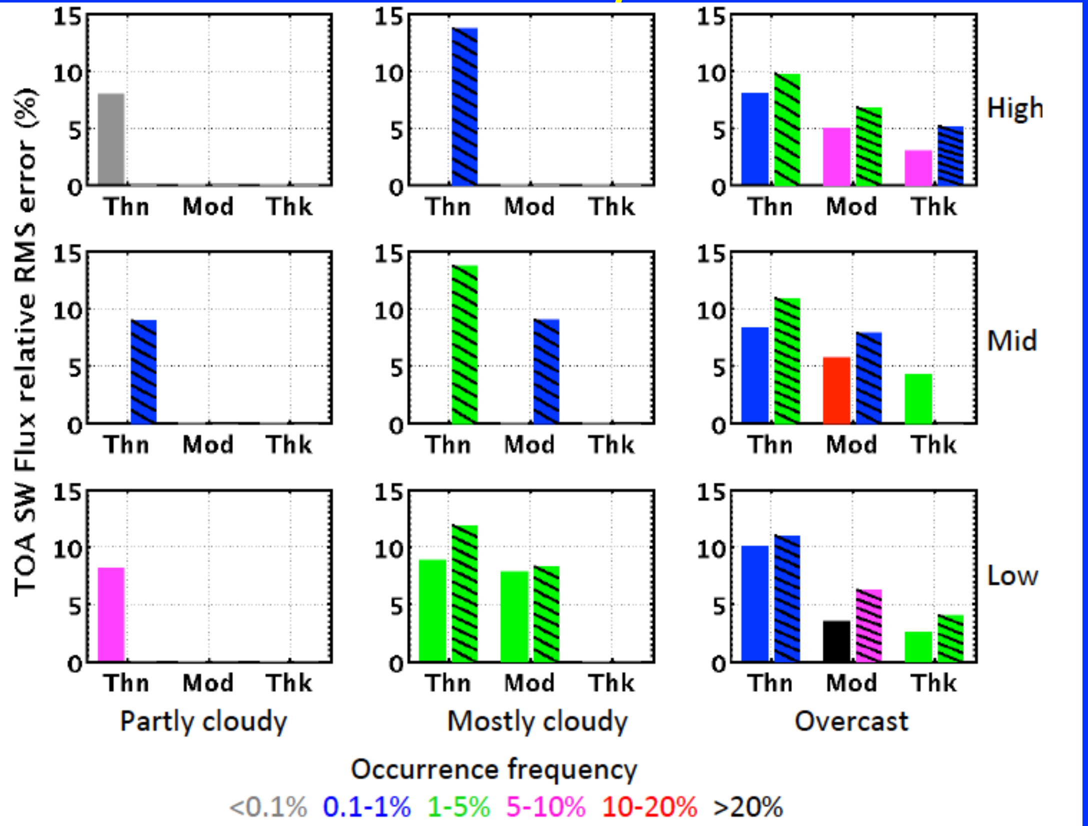
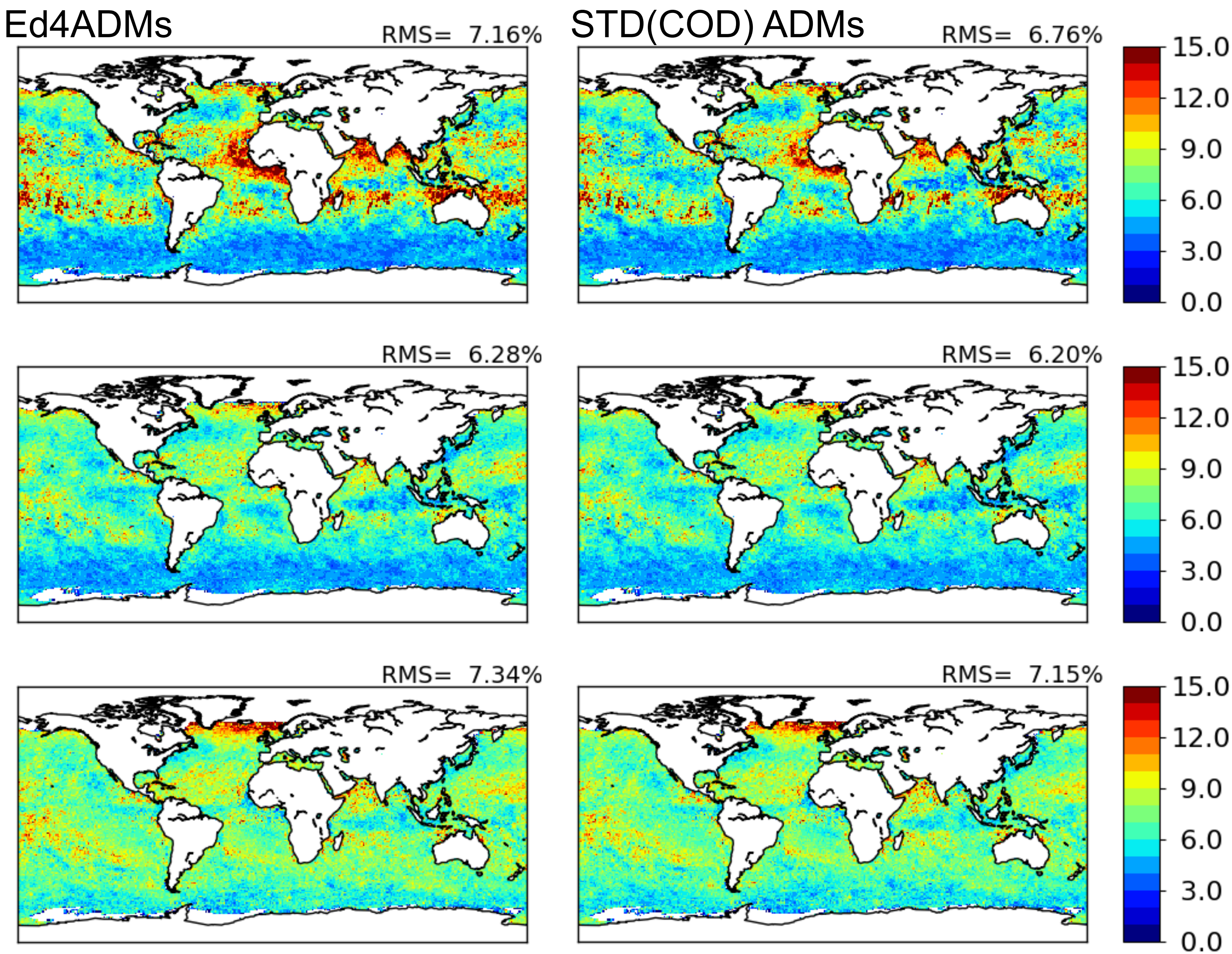


Figure 6. TOA SW flux consistency (%) between nadir- and oblique-viewing angles for different cloud types over ocean. The left bars are for single-layer clouds, and the right bars (hatched) are for multiple-layer clouds. The color of the bar indicates the occurrence frequency for each cloud type. Su et al. (2015), AMT

PCL: CF =0.1-40%	High: EP<440 hPa	Thin: τ < 3.35
MCL: CF=40-99%	Mid: EP = 440-680 hPa	Mod: τ = 3.35 -22.63
OVC: CF=99-100%	Low: EP > 680 hPa	Thick: τ > 22.63

Normalized radiance RMS error for January 2002

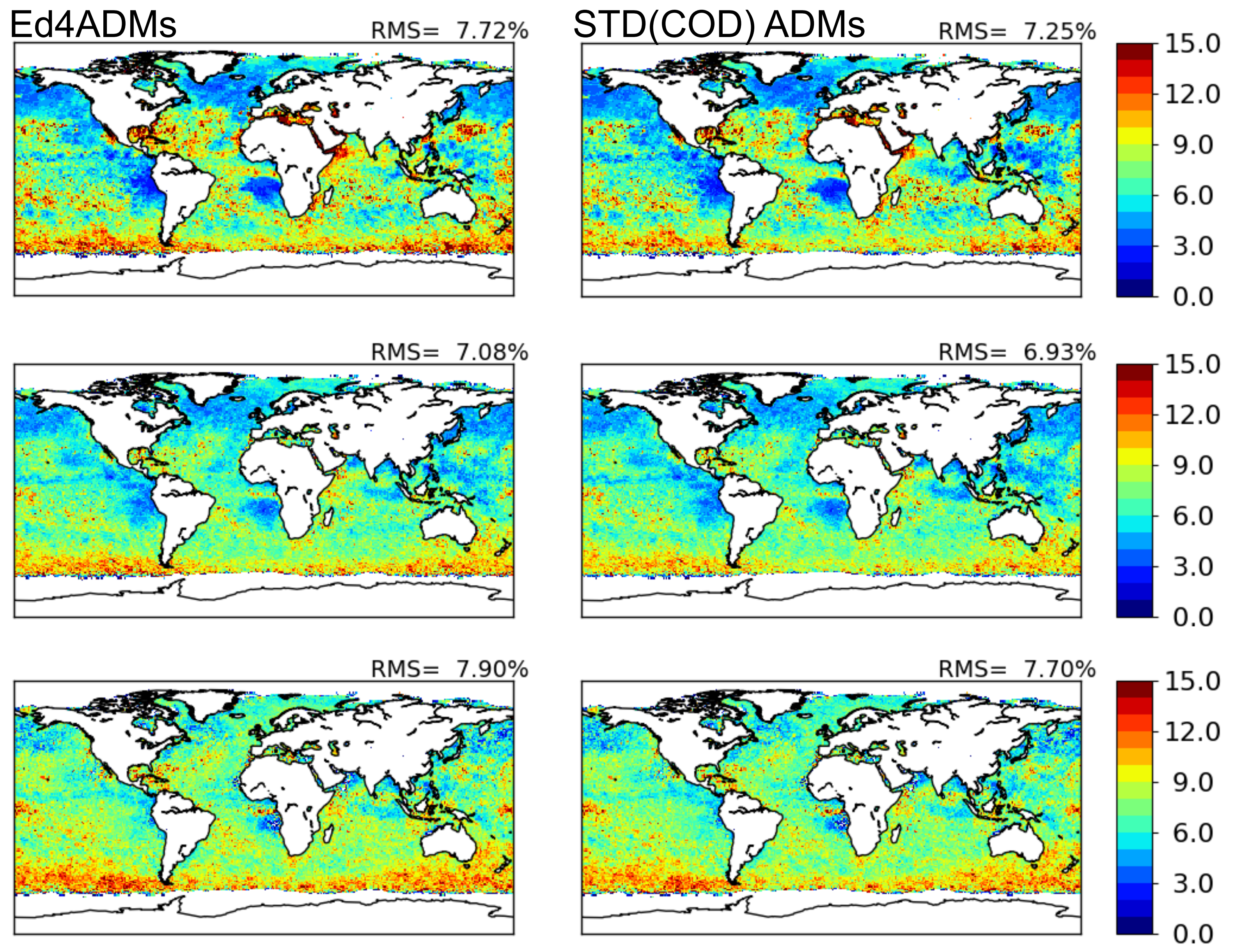


1st tercile

2nd tercile

3rd tercile

Normalized radiance RMS error for July 2002



1st tercile

2nd tercile

3rd tercile

Cloudy-sky LW/WN angular distribution models

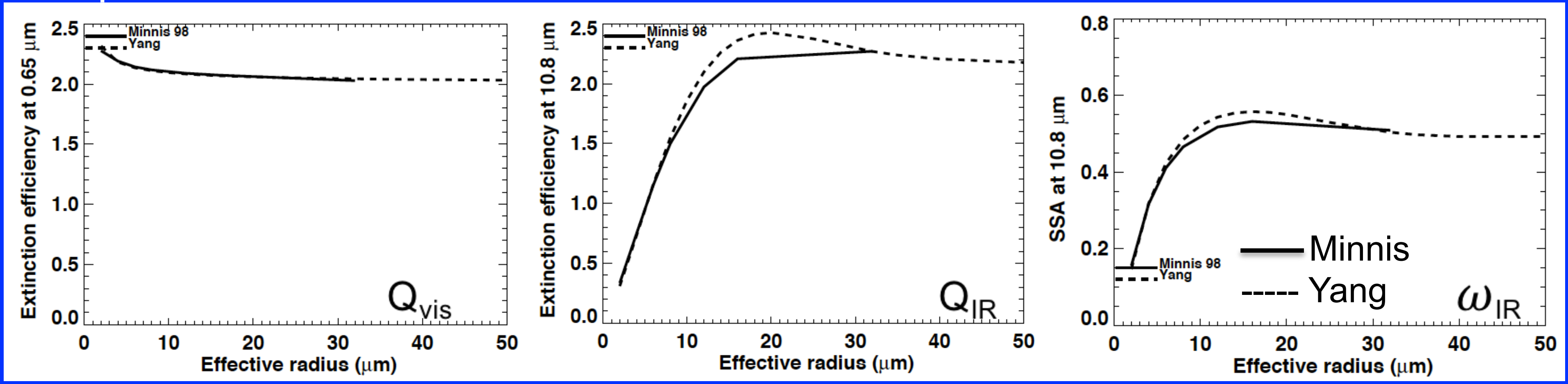
- Cloudy-sky LW ADMs are constructed based upon the relationship between radiance and 'pseudoradiance' (Ψ):

$$\Psi(w, T_s, T_c, f, \epsilon_s, \epsilon_c) =$$
$$(1-f)\epsilon_s B(T_s) + \sum_{j=1}^{2}\left[\epsilon_s B(T_s)(1-\epsilon_{c_j}) + \epsilon_{c_j} B(T_{c_j})\right] f_j$$

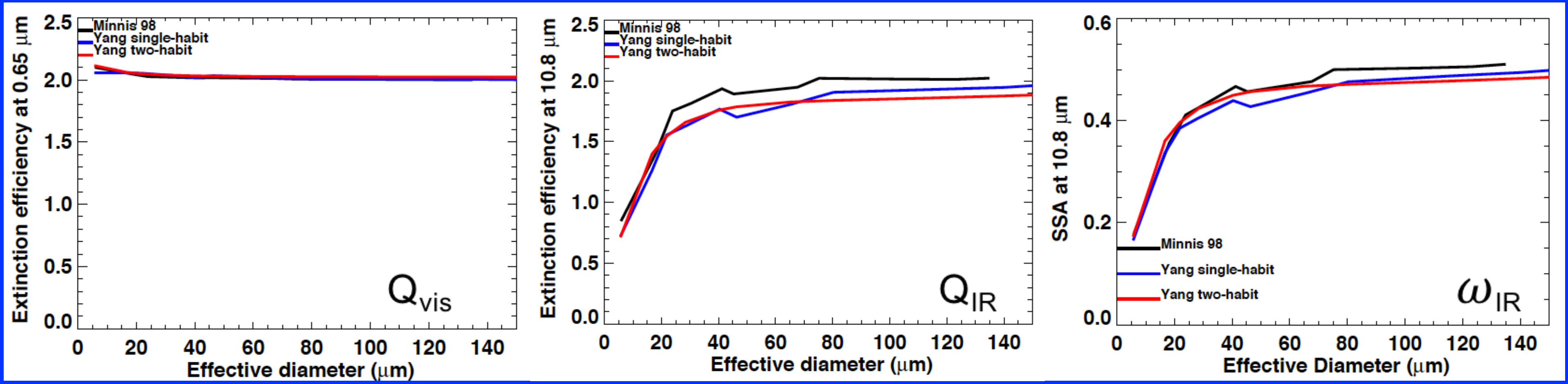
- Cloud infrared emissivity is : $\epsilon_c = 1 - e^{-\tau_a}$
- The IR absorption optical depth is: $\tau_a = (1-\omega_{IR})\tau_{IR}$
- The infrared optical depth: $\tau_{IR} = \tau_{vis}\dfrac{Q_{IR}}{Q_{vis}}$
- The visible and infrared extinction efficiency and the infrared scattering albedo are all based upon the values provided in Minnis et al. (1998) for various liquid and ice clouds.

Comparison of cloud optics

Liquid cloud

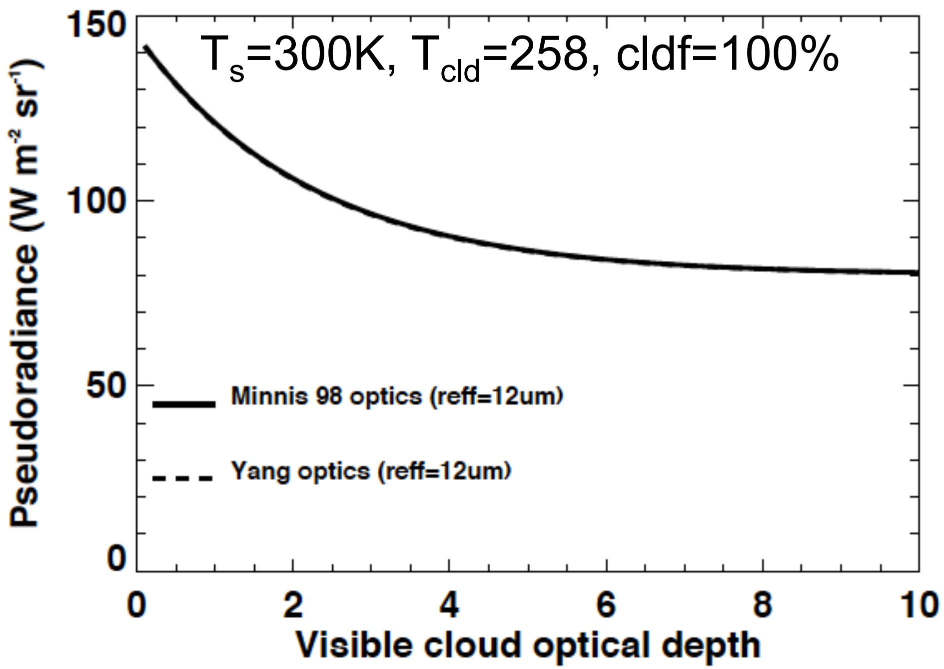


Ice cloud

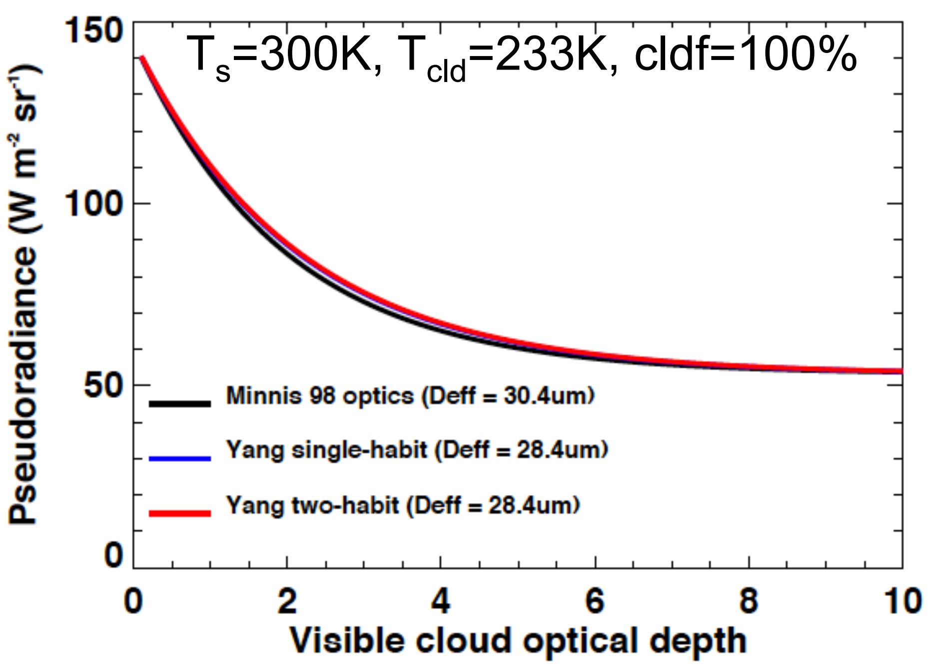


Impact on pseudoradiance calculation

Liquid cloud with r_{eff}=12 μm



Ice cloud with D_{eff}= 30 μm



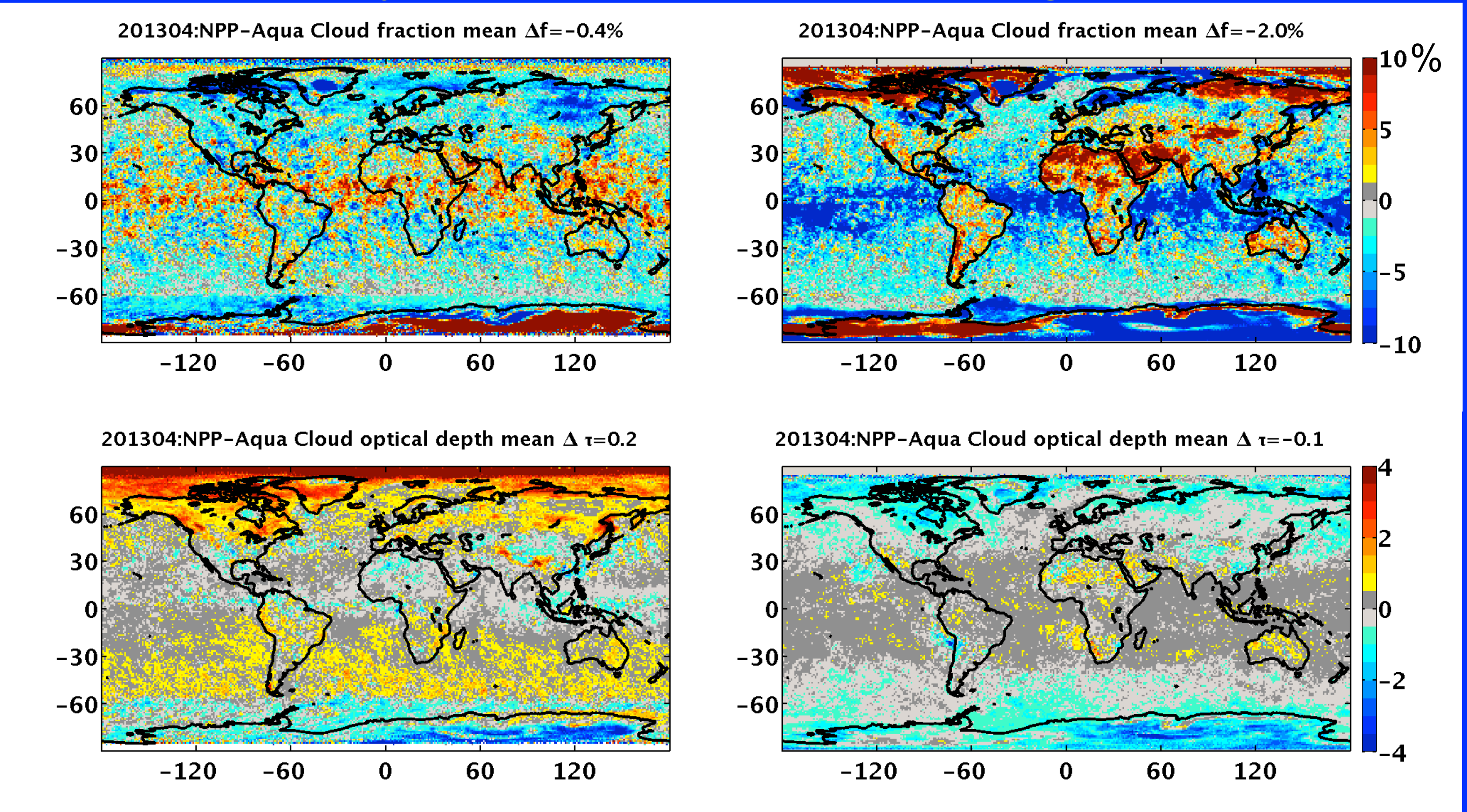
Quantify Suomi-NPP flux error caused by using Aqua ADMs

- Aqua ADMs are used to invert fluxes for CERES observations on NPP
- Footprint size for S-NPP is larger than that for Aqua.
- Cloud properties retrieved from VIIRS can also be different from those retrieved from MODIS.

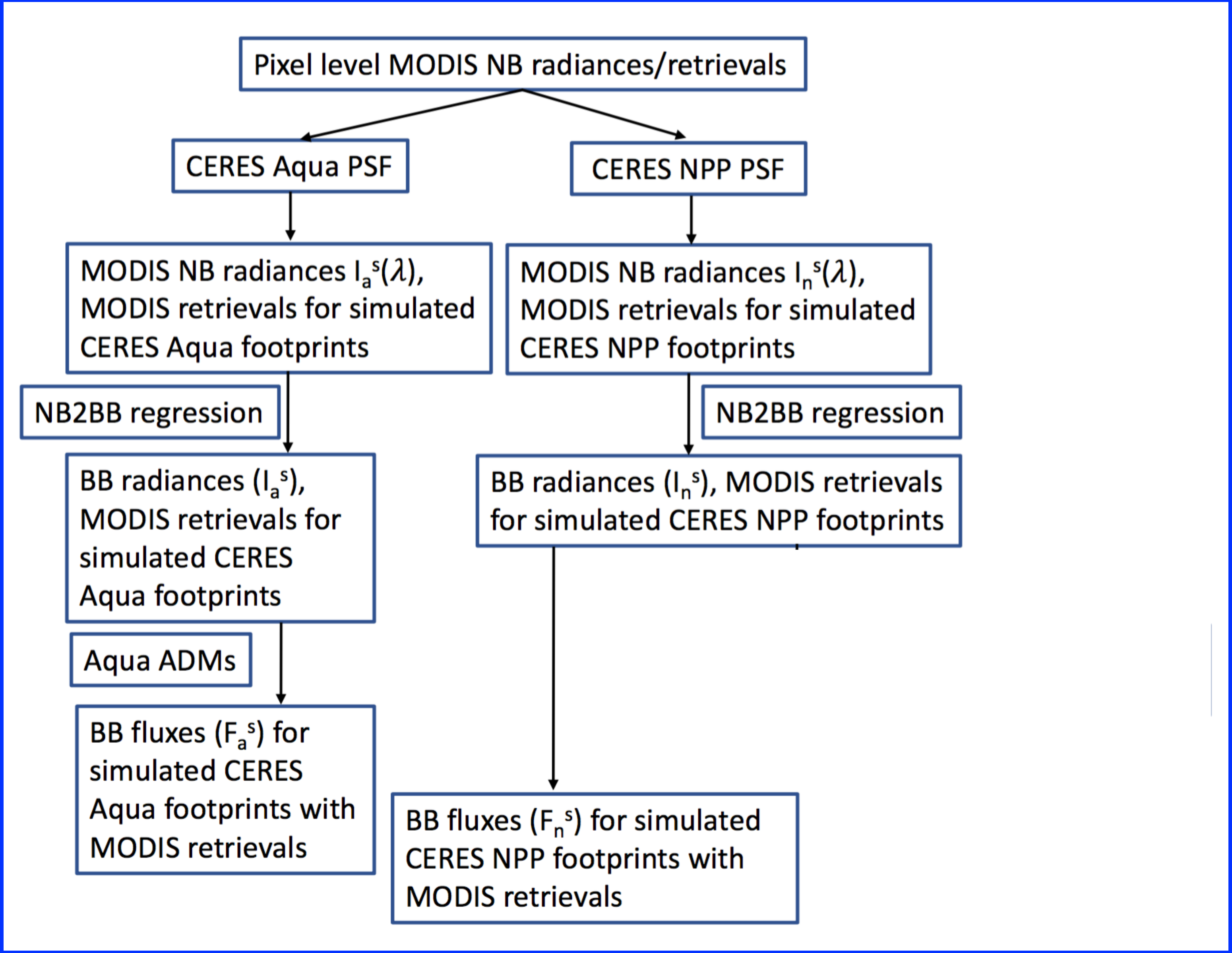
Daytime Nighttime

Δf

Δτ

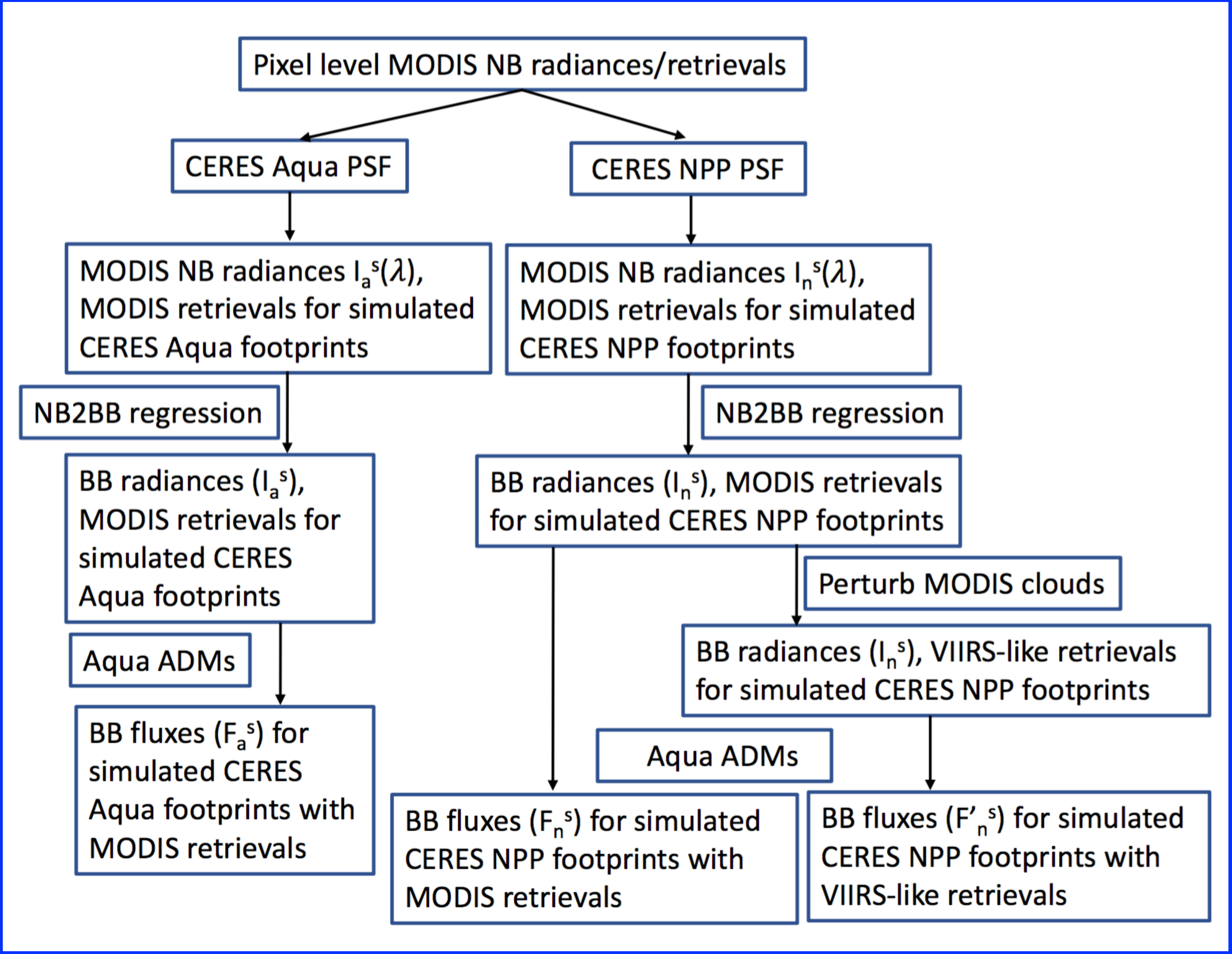


Simulate Aqua and NPP footprints to quantify flux error due to different footprint size and cloud property



Su et al. (2017), AMT

Simulate Aqua and NPP footprints to quantify flux error due to different footprint size and cloud property



Su et al. (2017), AMT

Flux errors due to footprint size and cloud property differences

- Footprint size difference between CERES instruments on Aqua and on Suomi-NPP leads to:
  - Underestimation of global monthly mean instantaneous SW flux by 0.4 Wm^{-2} and the RMS error is 2.4 Wm^{-2}.
  - A close to zero bias in global monthly mean LW flux and the RMS errors are 0.8 Wm^{-2} and 0.2 Wm^{-2} for daytime and nighttime.
  - Regionally, the differences are less than 4.0 and 1. 0 Wm^{-2} for SW and LW.
- Footprint size and cloud property difference between CERES instruments on Aqua and on Suomi-NPP leads to:
  - Overestimation of global monthly mean SW flux by 1.1 Wm^{-2} and the RMS error is increased to 5.2 Wm^{-2}.
  - LW RMS errors increase slightly to 0.9 Wm^{-2} and 0.5 Wm^{-2} for daytime and nighttime.
  - Regionally, SW flux error up to 20.0 Wm^{-2} and LW error up to 2.0 Wm^{-2} are observed over polar regions.

Plan to further evaluate the effect of scene identification on flux inversion