CERES Angular Distribution Model Working Group Report

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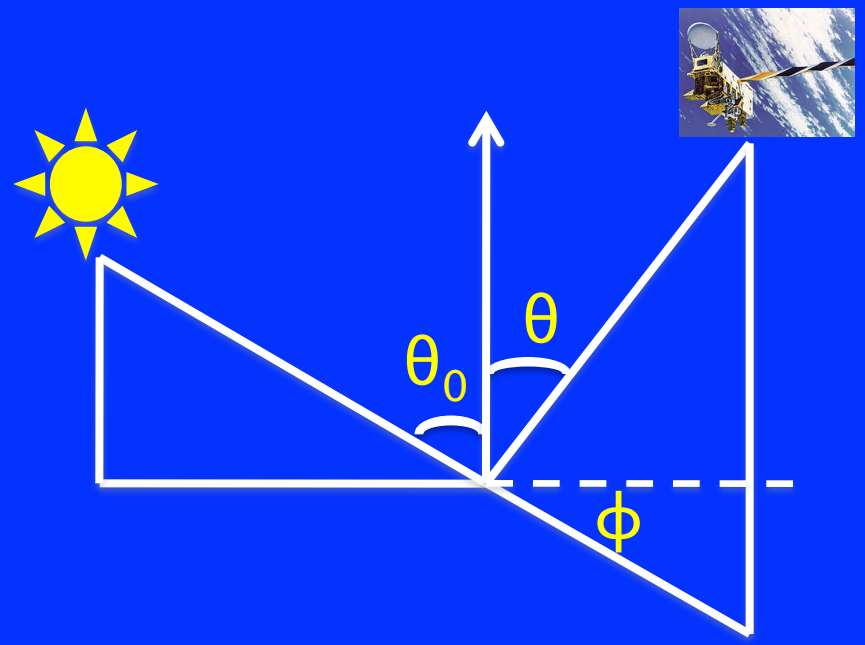
Outline

- ADMs over cloudy ocean: consider more categories in effective cloud phase;
- Clear-sky sea ice ADMs for low sea ice fractions;
- Consider azimuthal dependence of daytime clear-sky LW ADMs;
- Developing ADMs for CERES NPP, will one year of rotating azimuth plane scan (RAPS) data provide sufficient angular coverage?

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;



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

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

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

Angular distribution model over cloudy ocean

- For glint angle > 20°, or glint angle < 20° and ln(fT) > 6:
  - Average instantaneous radiances in each angular bin into 775 intervals of ln(fT), separately for liquid, mixed, and ice clouds;

$$\overline{\rho} = \frac{f_1\rho_1 + f_2\rho_2}{f_1 + f_2} \longrightarrow$$

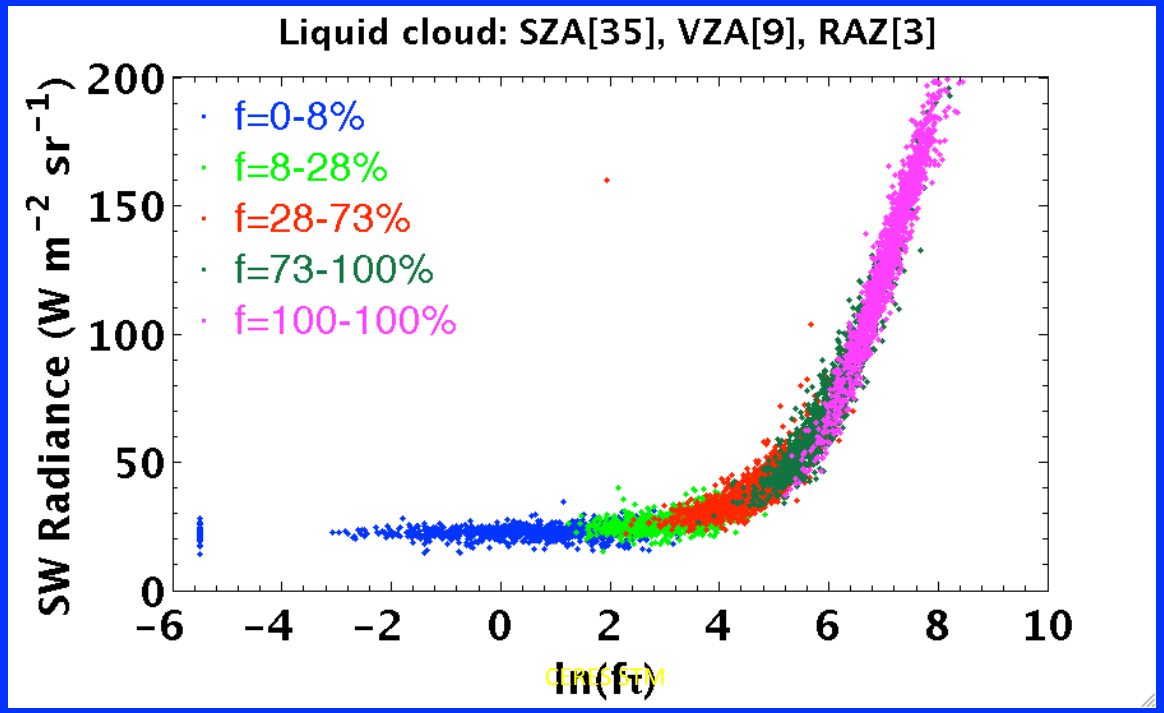
Liquid: $\overline{\rho} < 1.01$

Mixed: $1.01 \leq \overline{\rho} \leq 1.75$

Ice: $\overline{\rho} > 1.75$

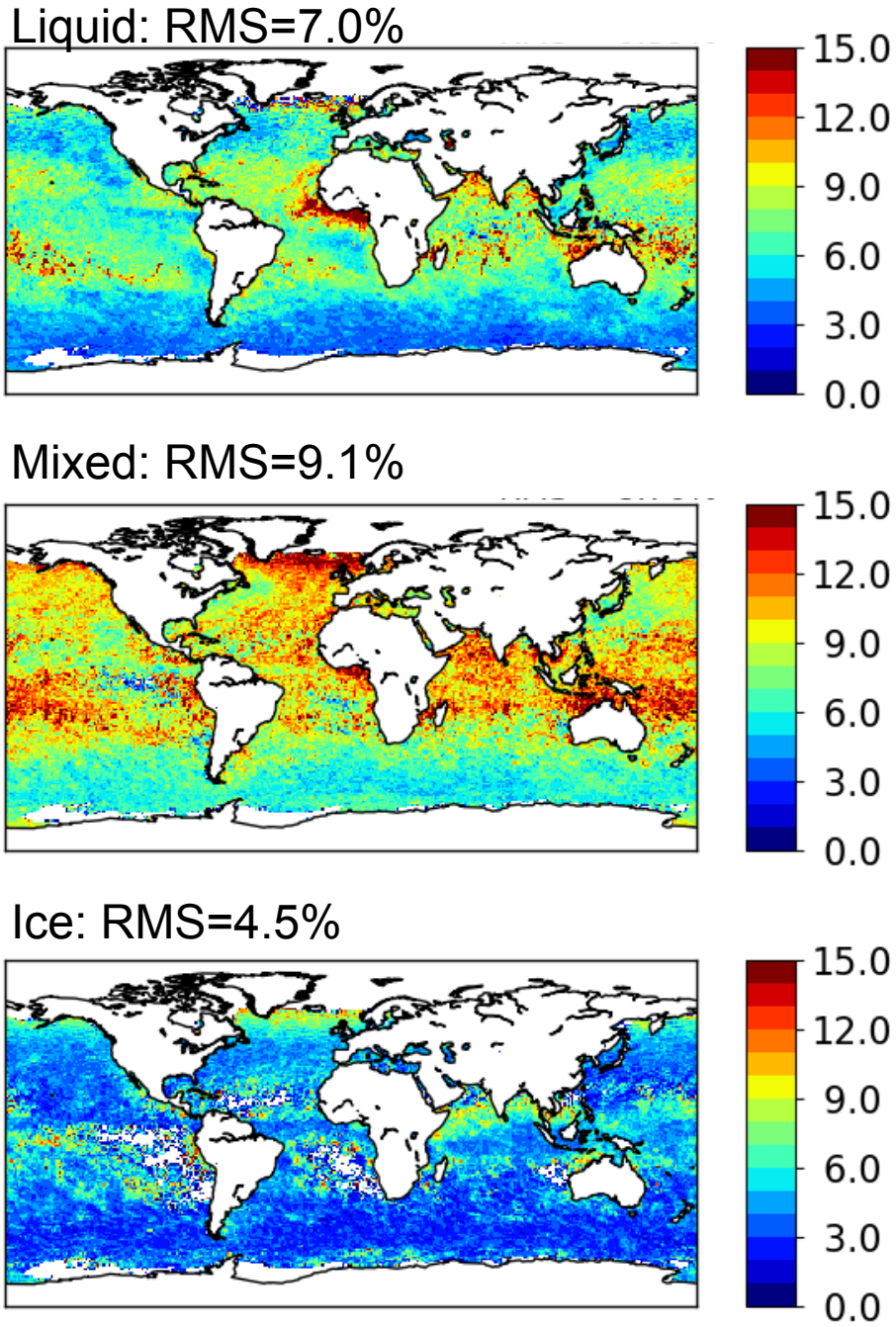
  - Apply a five-parameter sigmoidal fit to mean radiance and ln(fT);

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



Normalized RMS error calculated using ADMs constructed for three cloud phases

- RMS error between normalized ADM predicted radiance and normalized observed radiance is closely related to the ADM error;
- Mixed phase clouds have the largest RMS error, and ice clouds have the smallest RMS error.



Types of clouds over ocean: daytime retrievals from four seasonal months of 2008

Single layer clouds: Liquid (39.6%) $\overline{\rho} < 1.01$
Mixed (5.9%) $1.01 \leq \overline{\rho} \leq 1.99$
Ice (6.2%) $\overline{\rho} > 1.99$

Two layer clouds:

Liquid over liquid (2.7%)	Mixed over liquid (0.9%)	Ice over liquid (43.2%)
Liquid over mixed (0.1%)	Mixed over mixed (0.2%)	Ice over mixed (0.3%)
Liquid over ice (0.001%)	Mixed over ice (0.3%)	Ice over ice (0.9%)

- Single layer clouds contribute about 51.7%
- Mixed phase clouds contribute about 7.6%
- Most of the ice clouds are over liquid clouds (43.2% compares to 6.2% single layer ice clouds)

Redefine the mixed and ice clouds

- Cloud phases are defined as:

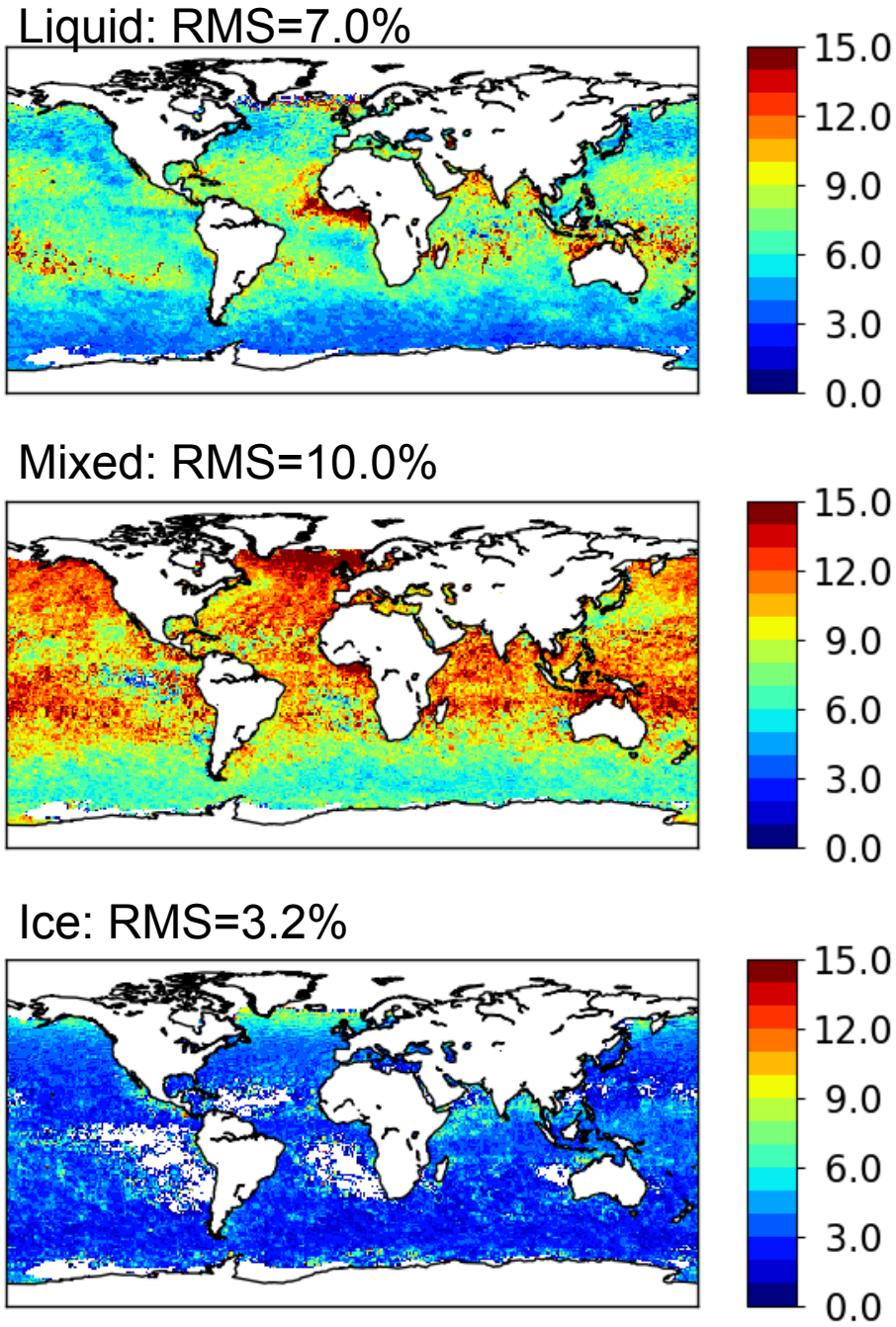
  Liquid: $\overline{\rho} < 1.01$

  Mixed: $1.01 \leq \overline{\rho} \leq 1.95$

  Ice: $\overline{\rho} > 1.95$

- Changing the ice phase definition towards higher phase value (less mixed clouds) reduced the RMS error from 4.5% to 3.2%;

- However, the RMS error for the mixed phase increased from 9.1% to 10.0%.



Split mixed clouds into two categories

- As most of the mixed clouds are from ice over water case, mixed clouds are further stratified into two categories:

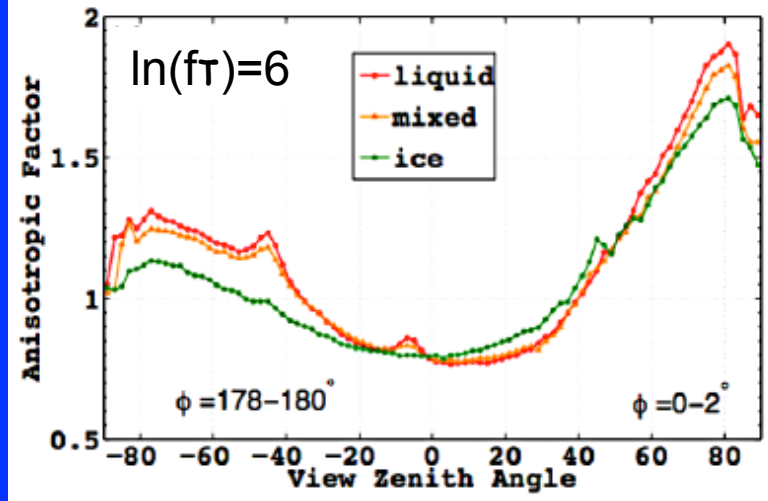
  Liquid: $\overline{\rho} < 1.01$

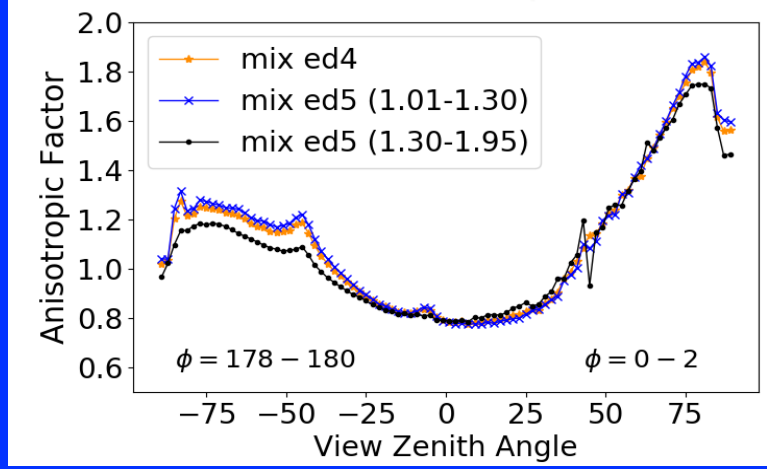
  Mixed 1: $1.01 \leq \overline{\rho} < 1.30$

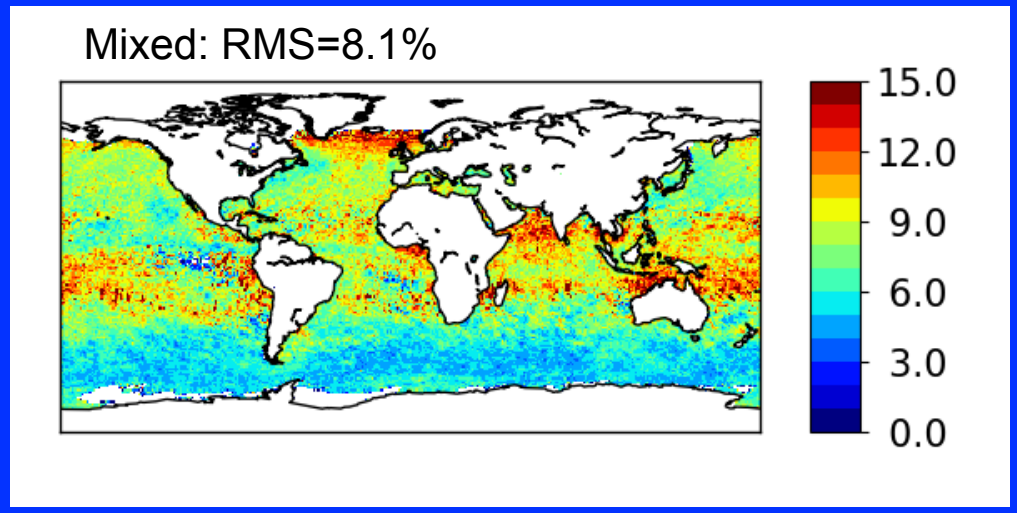
  Mixed 2: $1.30 \leq \overline{\rho} \leq 1.95$

  Ice: $\overline{\rho} > 1.95$

- The RMS error for the mixed phase clouds is the lowest among the different stratifications that we tested.







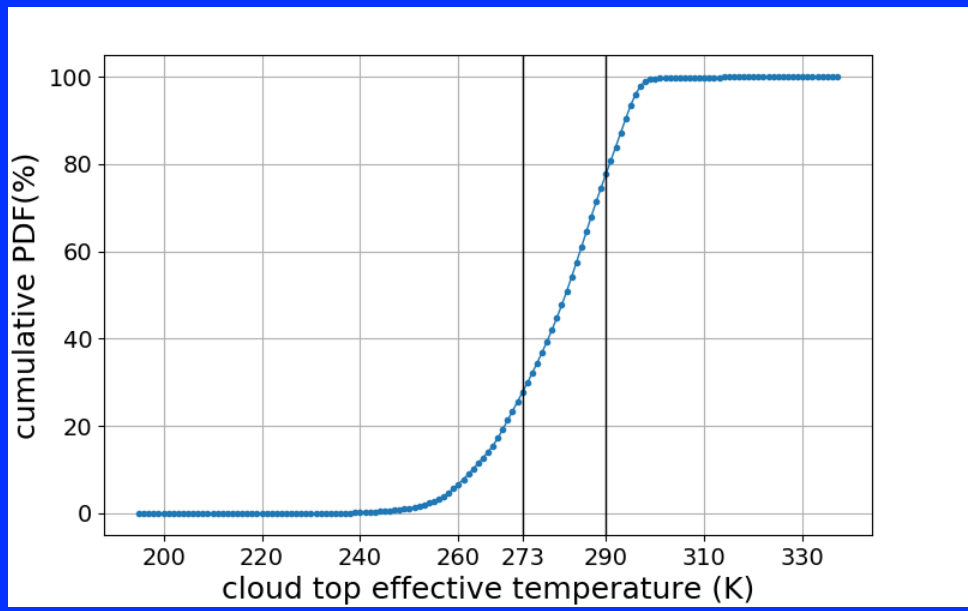
Liquid clouds

- To test whether the liquid cloud ADMs can be further improved, constructing three liquid cloud ADMs based upon the effective cloud top temperature:

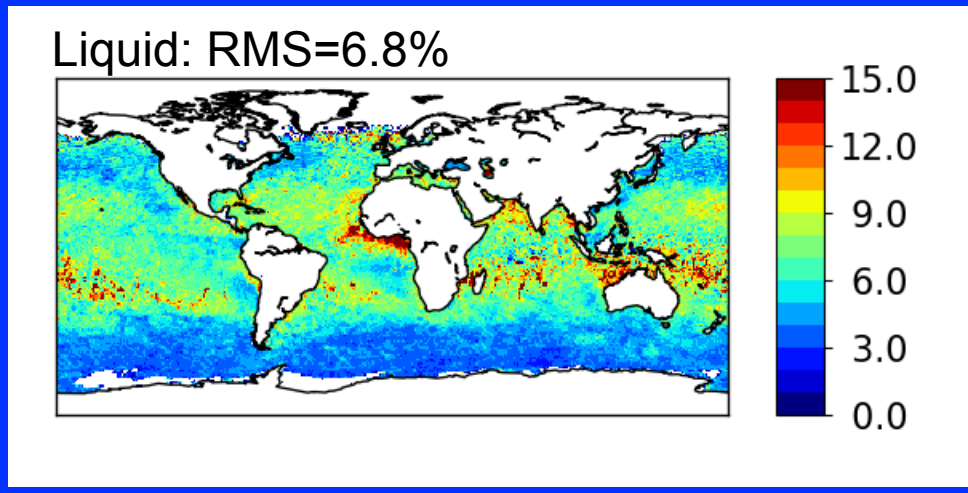
  Cold: $T_e \leq 273K$

  Cool: $273K < T_e \leq 290K$

  Warm: $T_e > 290K$

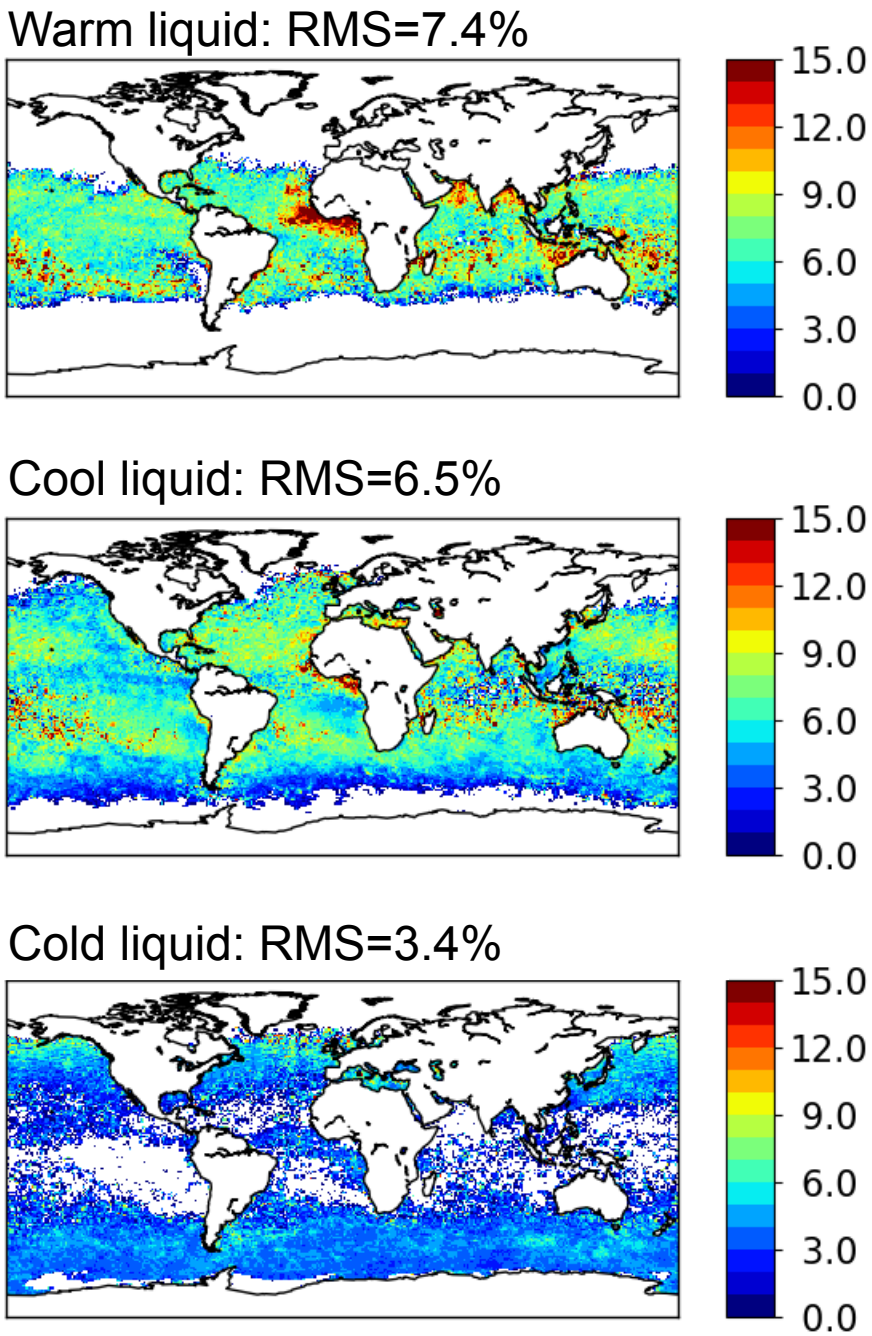


- The RMS error for liquid clouds improved slightly, decreasing from 7.0% (without T_e stratification) to 6.8% .



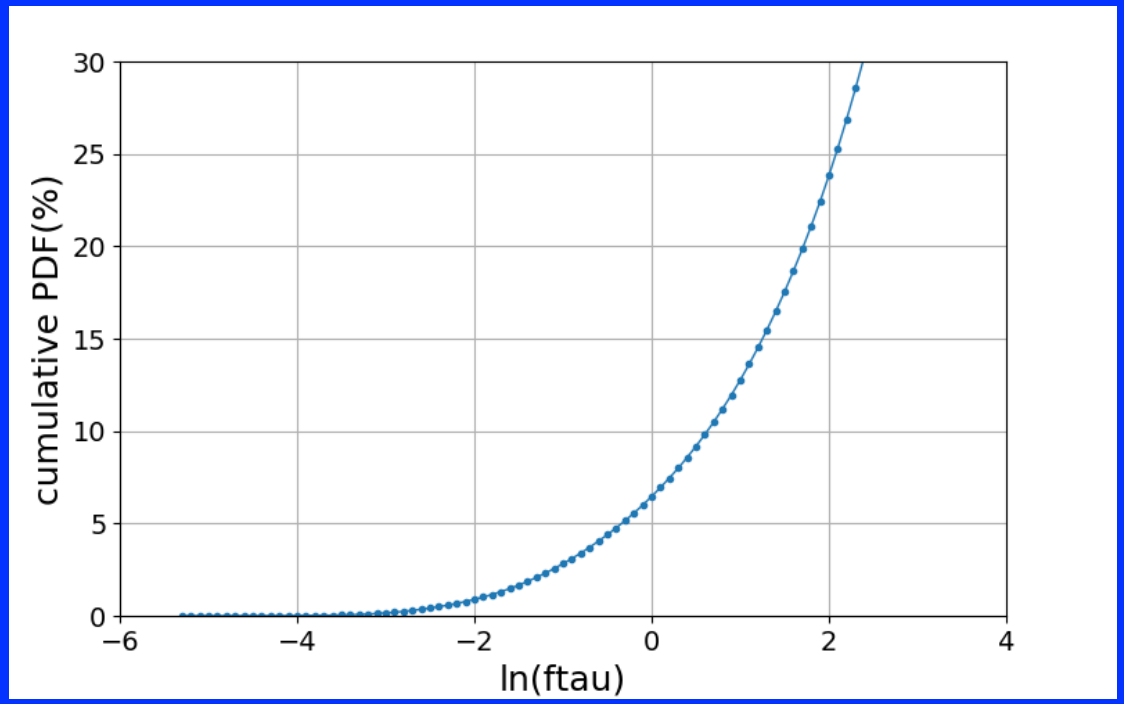
RMS error for the three types of liquid clouds

- Warm liquid clouds have the largest RMS error, and the RMS error is elevated near the aerosol source regions;
- Cold liquid clouds have the smallest RMS error, even in regions near the aerosol source regions.



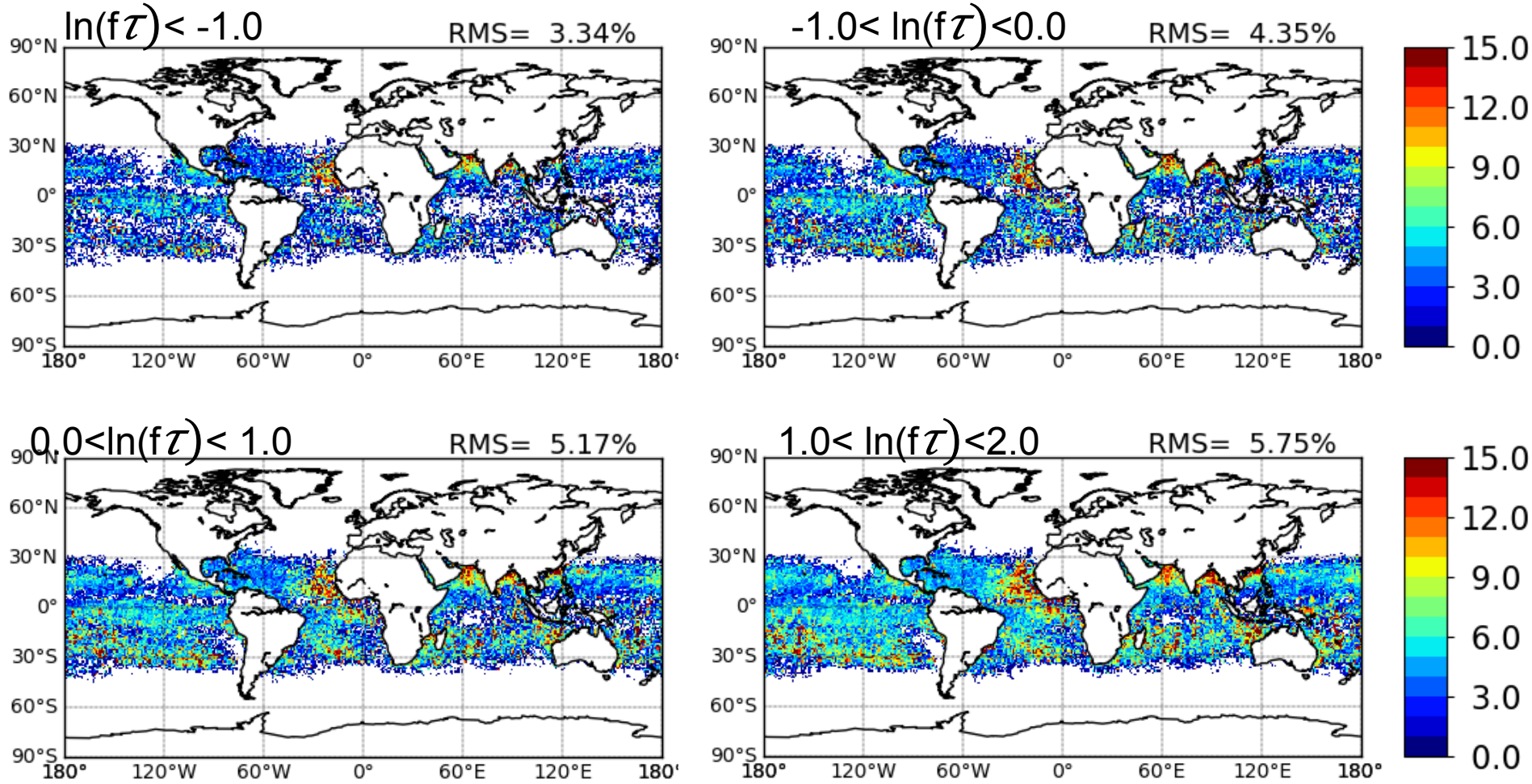
A lot of the warm liquid clouds are very thin

Cumulative PDF of ln(fτ) for warm (T_e>290 K) liquid cloud

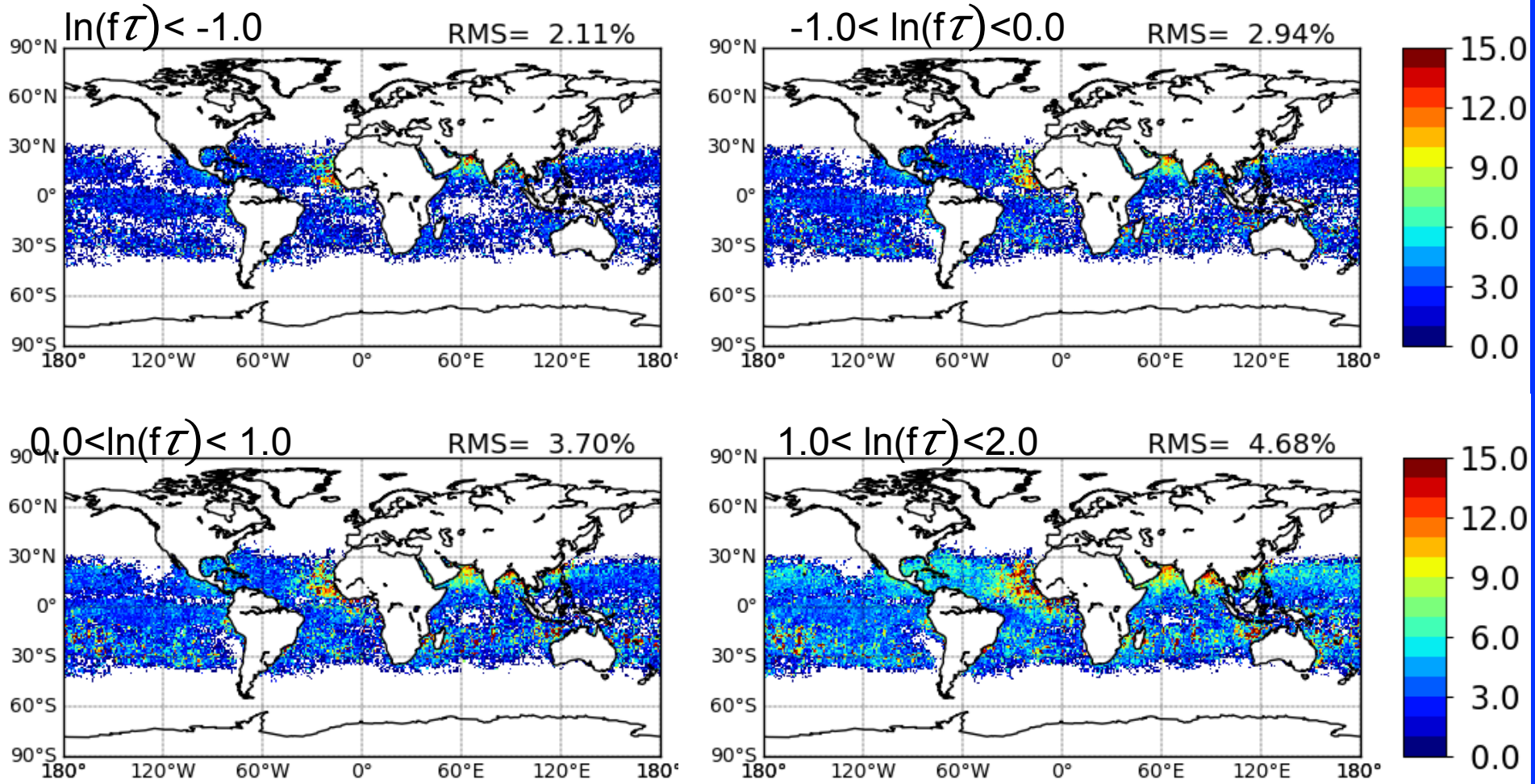


ln(fτ)	percentage	f=100%	f=10%
<0	7%	$ln(f\tau)=0$ τ=0.01	$ln(f\tau)=0$ τ=0.1
<1	13%	$ln(f\tau)=1$ τ=0.03	$ln(f\tau)=1$ τ=0.3
<2	24%	$ln(f\tau)=2$ τ=0.07	$ln(f\tau)=2$ τ=0.7

Warm liquid clouds with small ln(fτ): RMS error calculated using cloudy-ocean ADMs



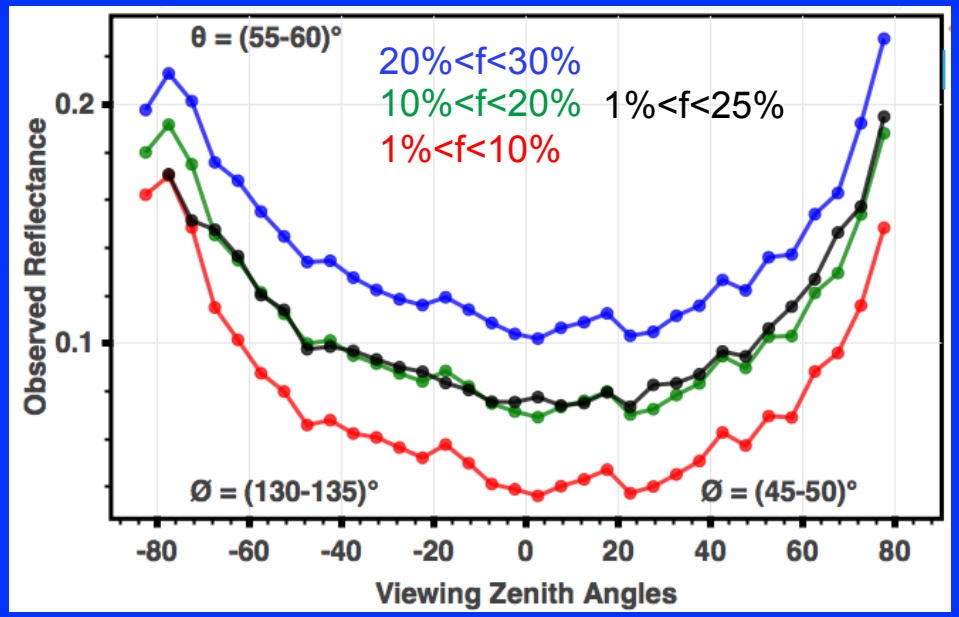
Warm liquid clouds with small ln(fτ): RMS error calculated using clear-ocean ADMs

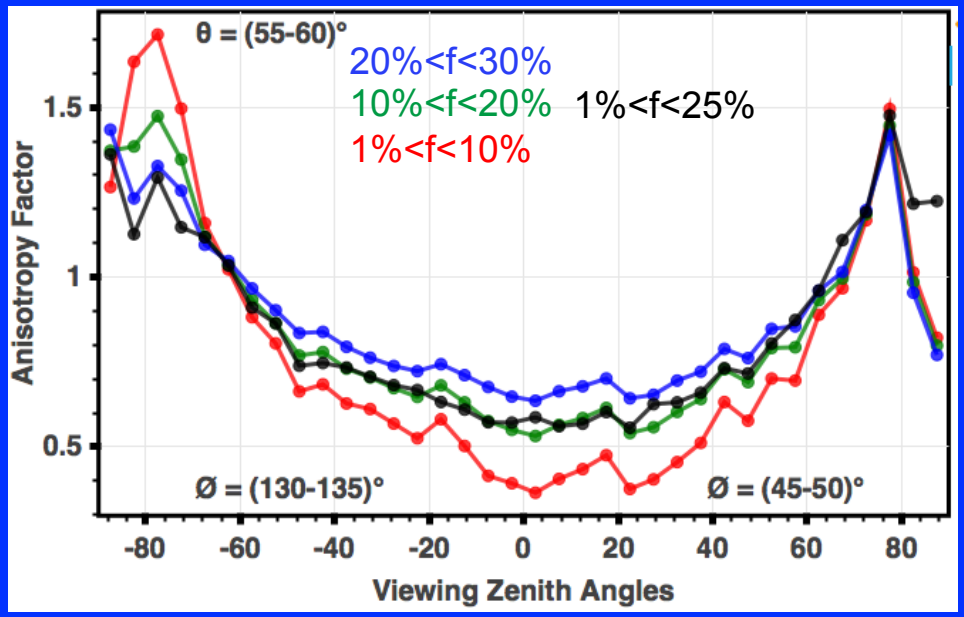


Clear-sky Sea Ice ADMs

- Clear-sky sea ice ADMs were developed for discrete sea ice fraction bins;
- When 10% sea ice fraction bins are used, both reflectance and anisotropic factors show sensitivity for low sea ice fractions;
- Fluxes can increase up to 10 Wm^{-2} for clear-sky low sea-ice fraction footprints, but the overall effect on clear-sky sea ice flux is small due to the sample size of these footprints.

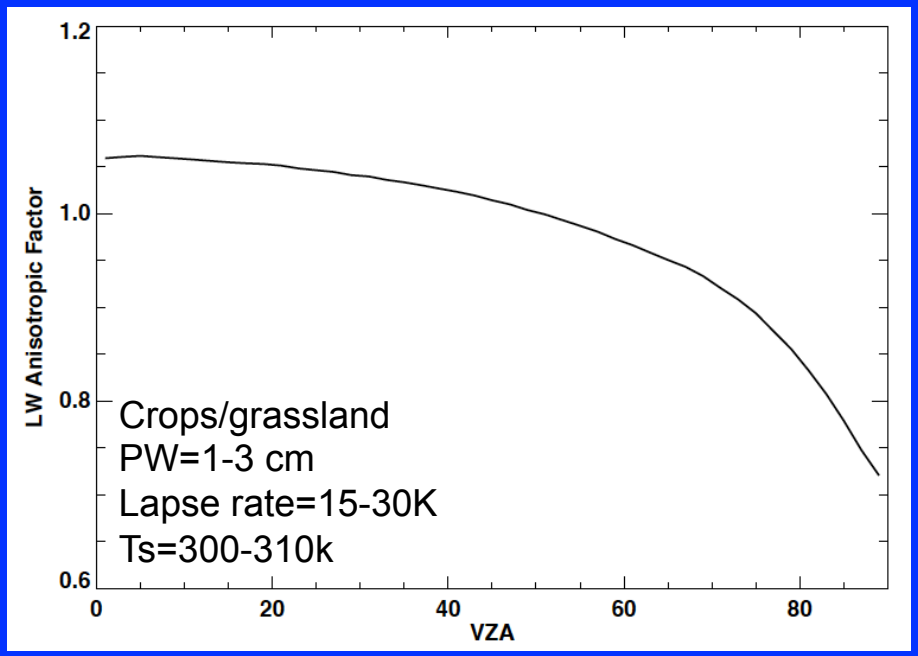
Clear-sky sea ice ADMs
Sea Ice fraction ≤1%
1% < Sea Ice fraction ≤25%
25% < Sea Ice fraction ≤50%
50% < Sea Ice fraction ≤75%
75% < Sea Ice fraction <99%
99% ≤ Sea Ice fraction, SIBI ≤0.85
99% ≤ Sea Ice fraction, 0.85<SIBI ≤0.935
99% ≤ Sea Ice fraction, SIBI >0.935





Clear-sky daytime LW ADM over land/desert

- Clear-sky LW ADMs were developed for discrete intervals of precipitable water, lapse rate, and surface skin temperature as a function of viewing zenith angle;
- Minnis et al (2004) noted that the shadowing by vegetation and landforms can cause azimuthal variations of the LW radiance;
- Examine the sensitivity of daytime LW ADMs to solar zenith angle, relative azimuth angle, and surface variability (SV) following the method used in Minnis et al. (2004).



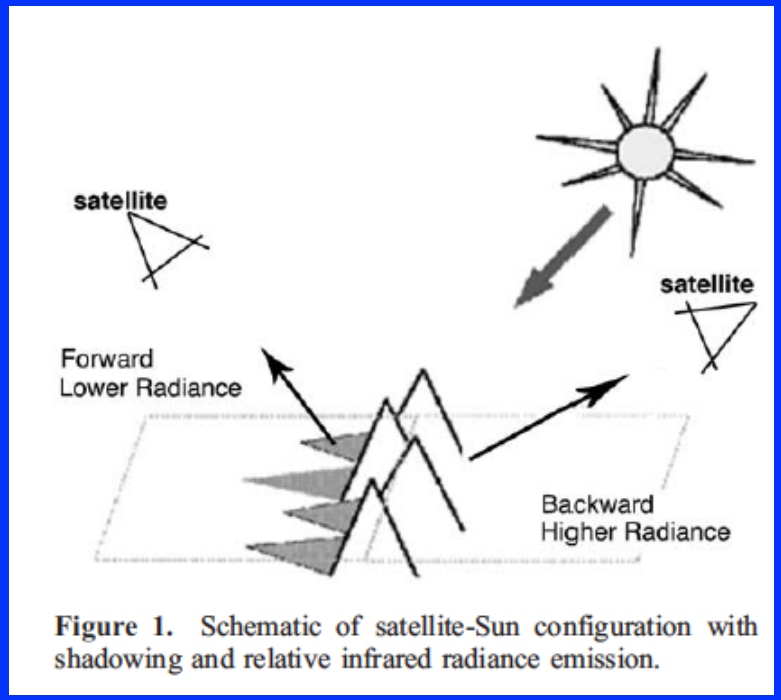


Figure 1. Schematic of satellite-Sun configuration with shadowing and relative infrared radiance emission.

From Minnis et al. (2004)

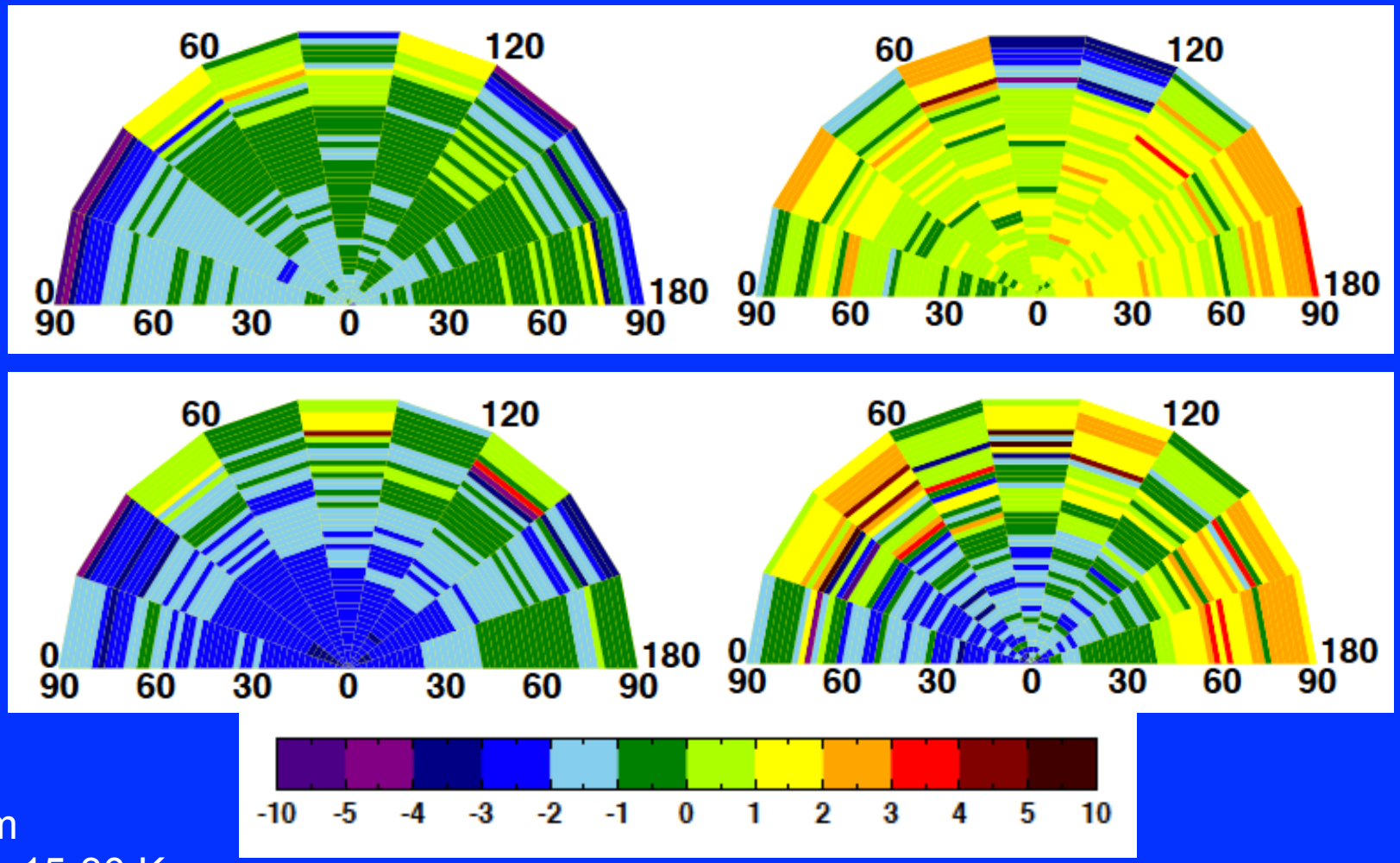
Mean radiance difference between I(SZA, RAA, VZA, SV) and I(VZA) over crops/grassland

Surface Variability: low

Surface Variability: high

SZA=0-48°

SZA=48-70°



PW=1-3 cm
Lapse rate=15-30 K
Ts=300-310 K

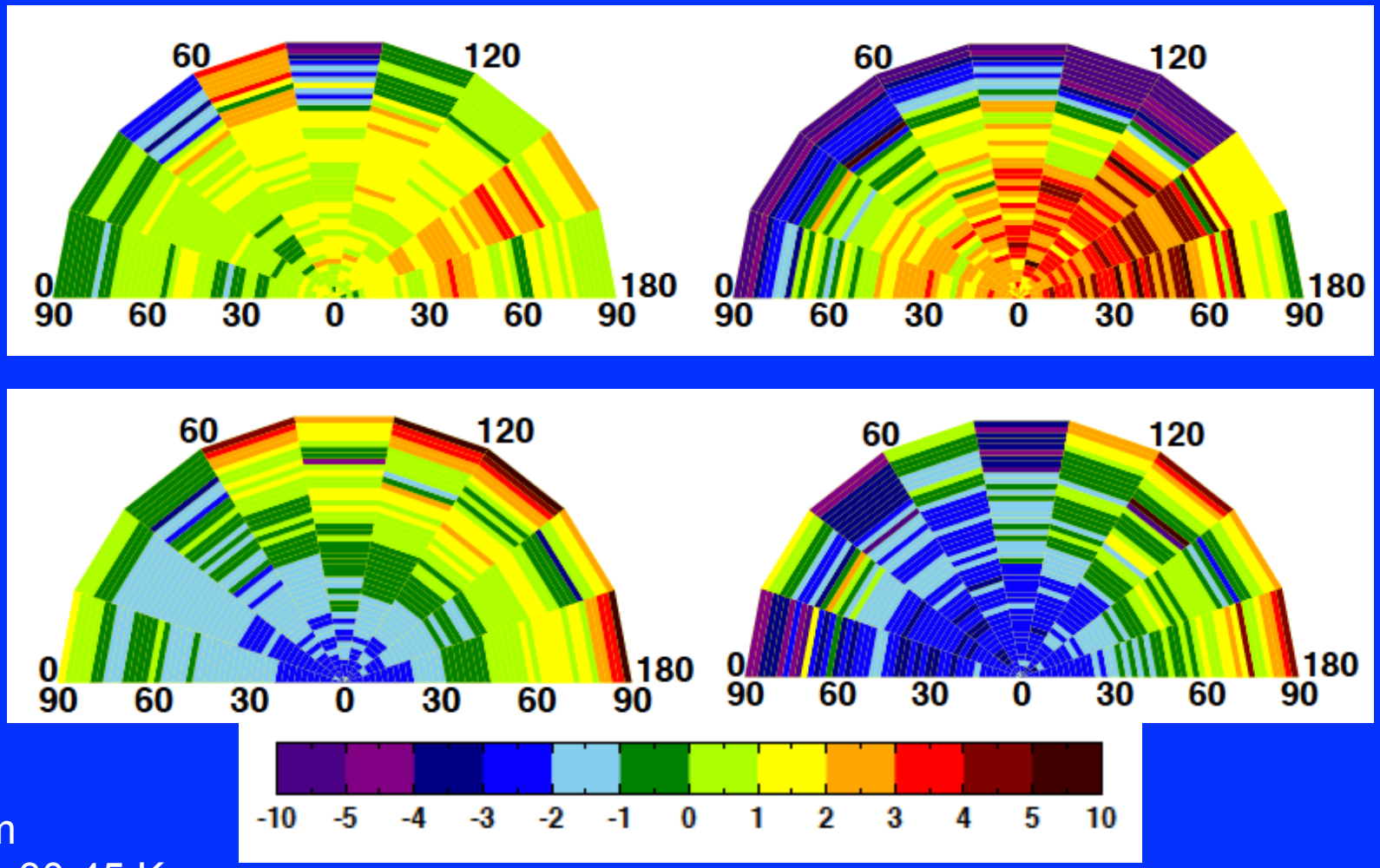
Mean radiance difference between I(SZA, RAA, VZA, SV) and I(VZA) over dark desert

Surface Variability: low

Surface Variability: high

SZA=0-48°

SZA=48-70°



PW=0-1 cm
Lapse rate=30-45 K
Ts=300-310 K

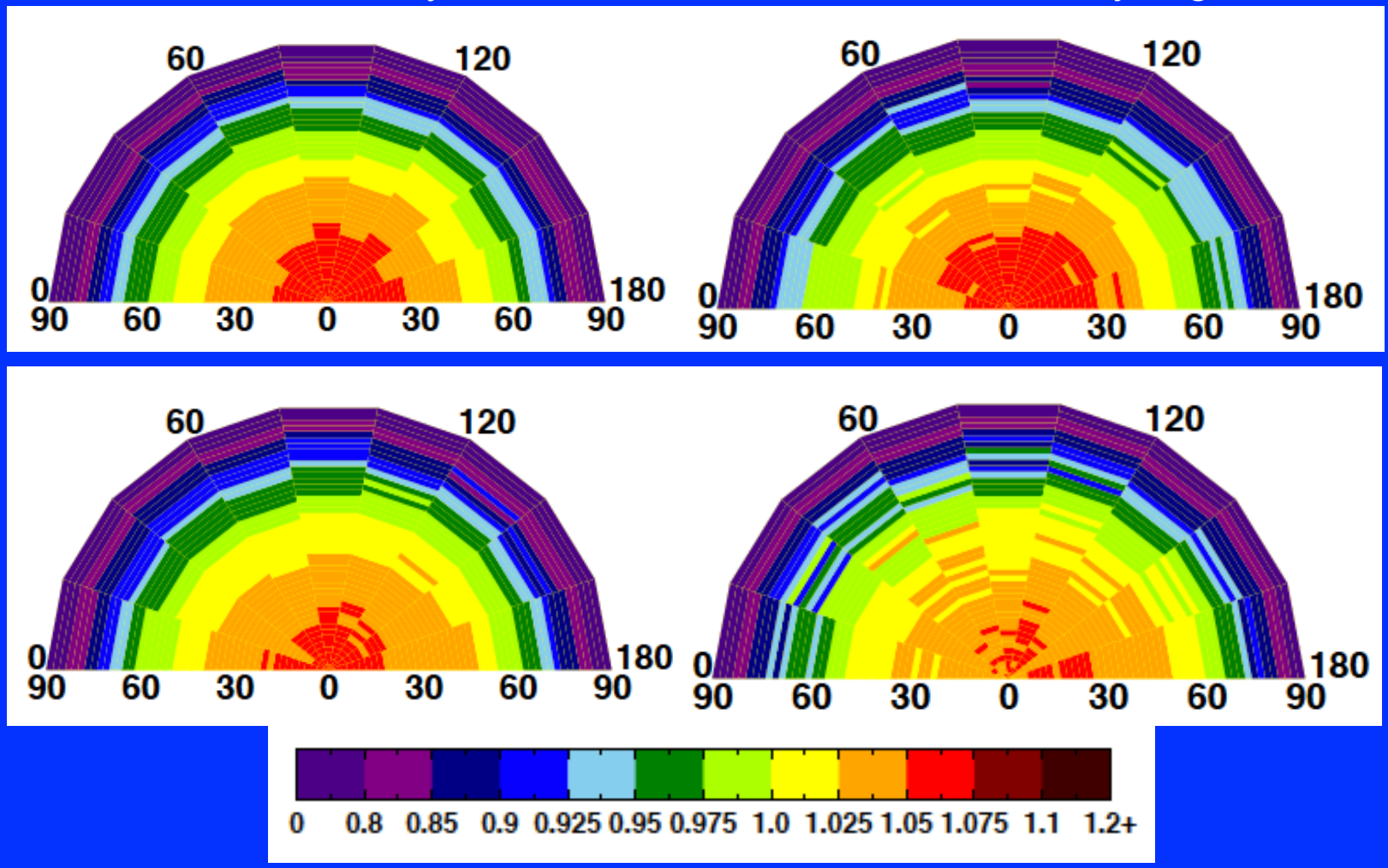
Anisotropic factors over crops/grassland

Surface Variability: low

Surface Variability: high

SZA=0-48°

SZA=48-70°



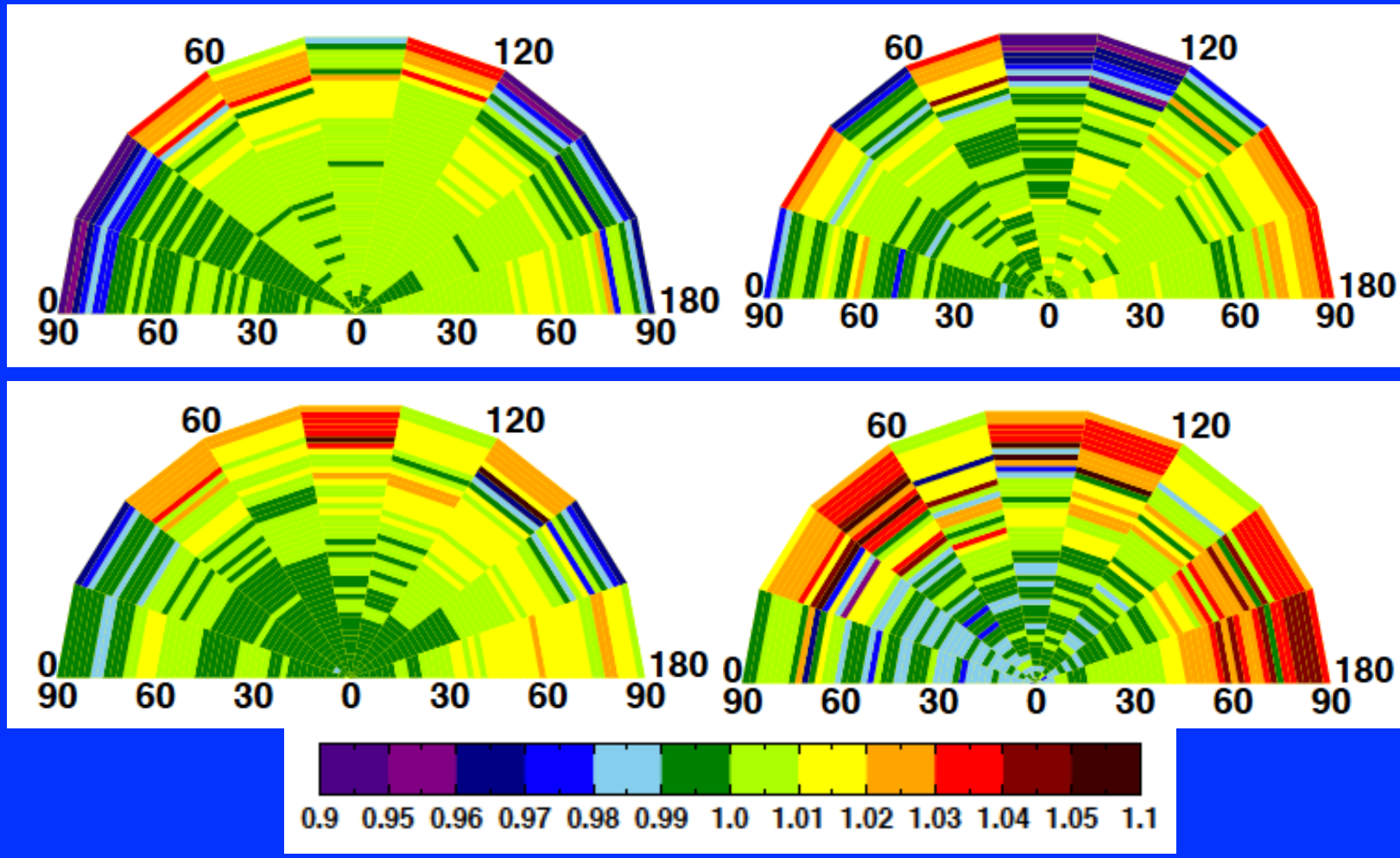
Ratio of R(SZA, VZA, RAA, SV)/R(VZA) over crops/grassland

Surface Variability: low

Surface Variability: high

SZA=0-48°

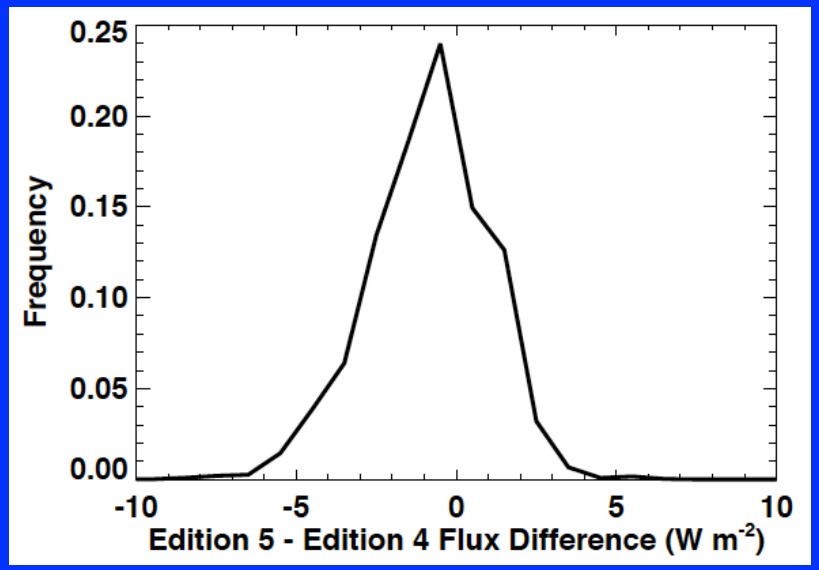
SZA=48-70°



Impact on daytime clear-sky LW flux

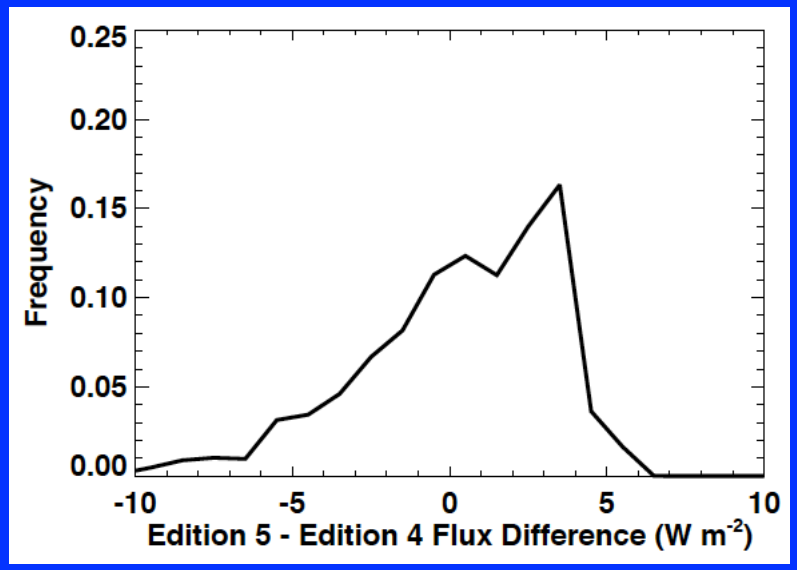
- Clear-sky daytime LW ADMs consider the solar zenith angle, relative azimuth angle, and surface variability can alter the instantaneous LW flux by up to 10 Wm^{-2}.
- For a given scene type, the mean flux change is less than 1 Wm^{-2} with RMS errors about 2-3 Wm^{-2}.

Crops/Grassland



ΔF=-0.9 Wm-2
RMS=2.1 Wm-2

Dark Deserts

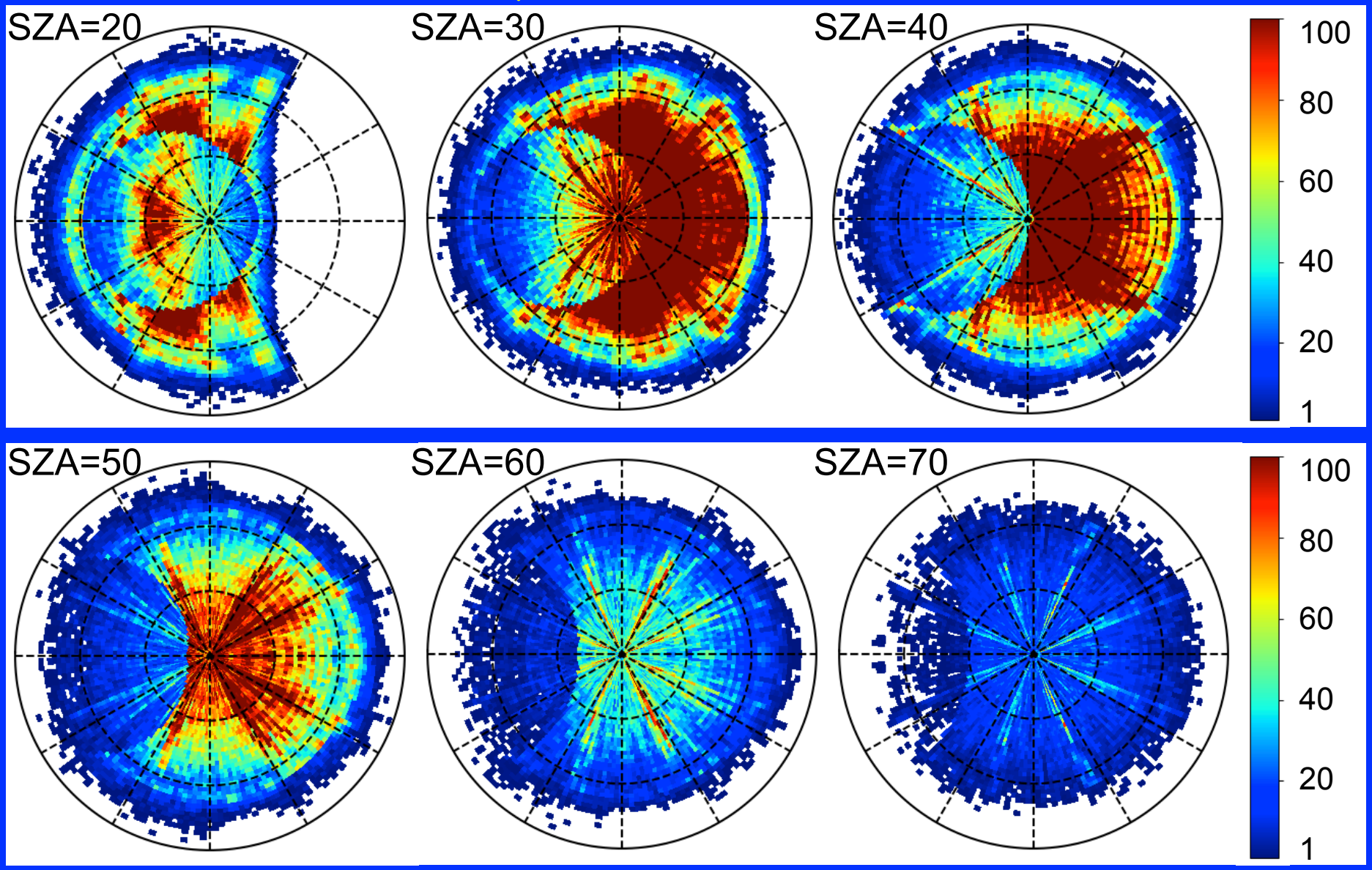


ΔF=-0.3 Wm-2
RMS=3.1 Wm-2

Placing NPP in rotating azimuth plane scan (RAPS) mode to collect data for ADM development

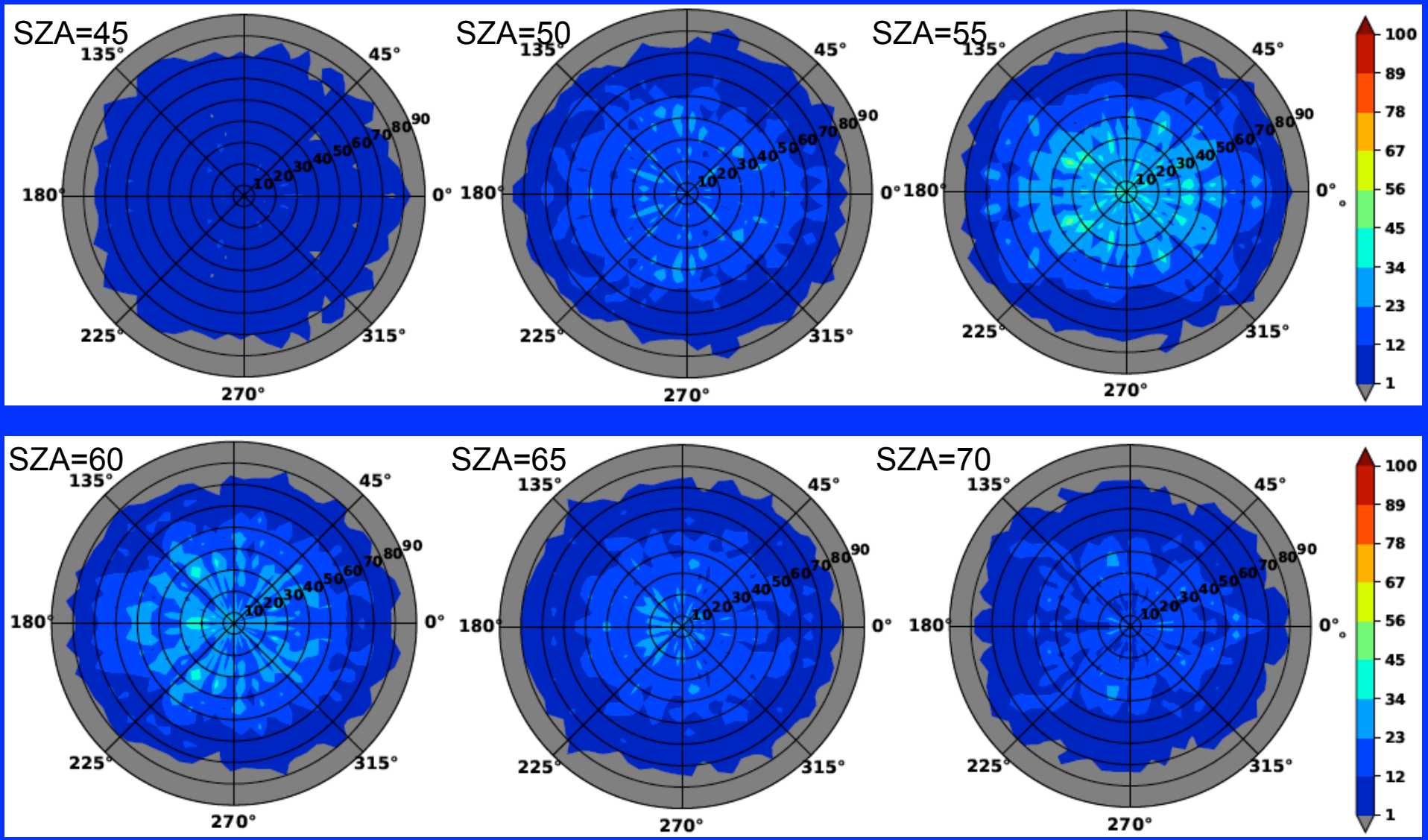
- Use NOAA20 (JPSS1) to continue the CERES Aqua record once Aqua's orbit starts to drift;
- Aqua will be used as the "bridge" for inter-calibrating NPP and NOAA20;
- Once NOAA20 CERES is stable and has a minimum of one year of measurements, we plan to put NPP into RAPS mode to collect data for constructing ADMs;
- Once the Aqua (also Terra) orbit starts to drift, we will consider to put them into RAPS mode to augment the SZAs coverage;
- Using one year of Aqua RAPS data (2004, total of 321 days) to investigate the angular coverage over different scene types.

Number of samples in each angular bin over clear-sky ocean from 1 year of RAPS data

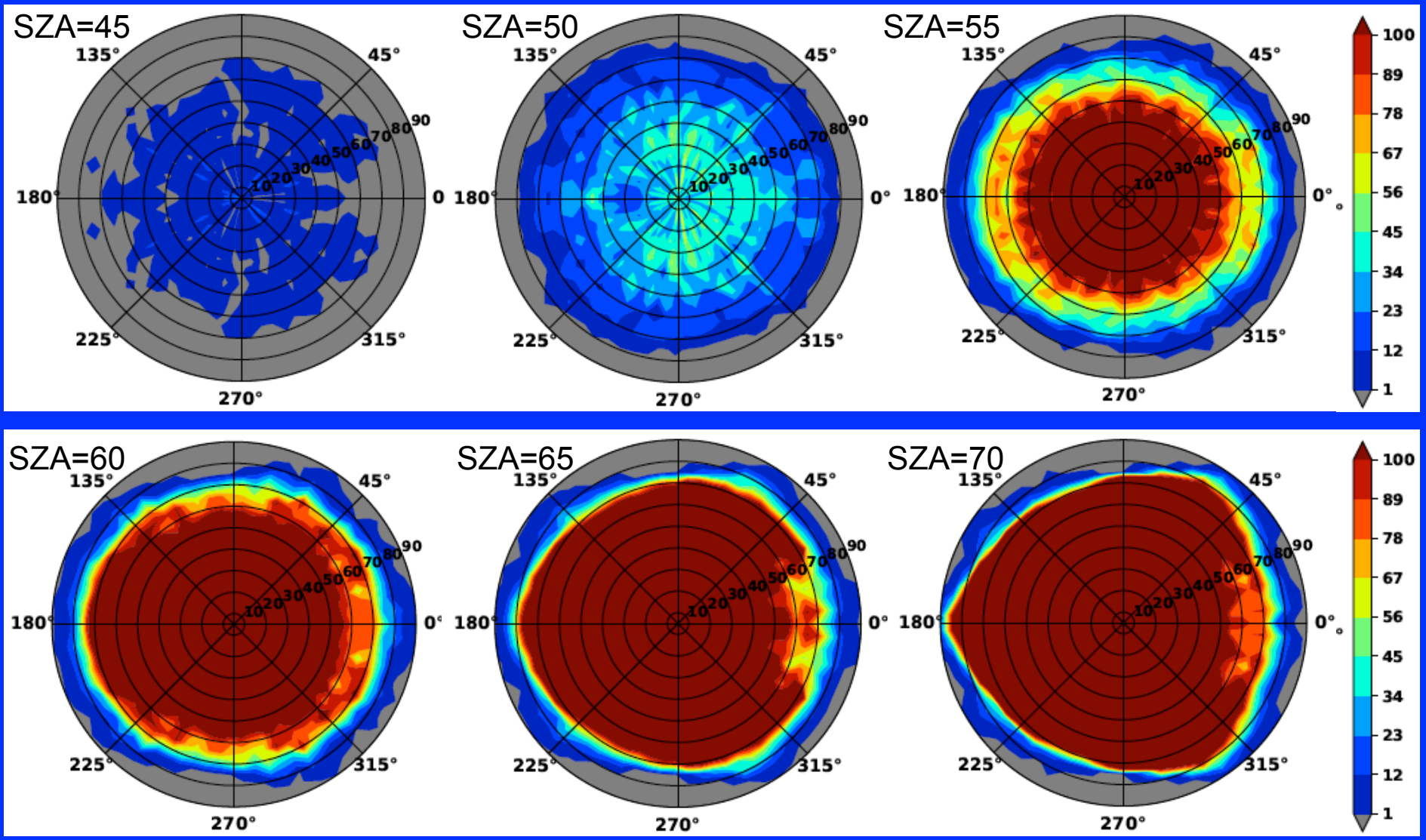


*Wind speed 4-6 m/s

Number of samples in each angular bin over clear-sky sea ice (1%<sea ice fraction<25%) from 1 year of RAPS data



Number of samples in each angular bin over clear-sky sea ice (sea ice fraction>99%, and mid SIBI bin) from 1 year of RAPS data



Summary

- Adding more cloud phase bins reduces the ADM uncertainty
- Clear-sky daytime LW ADMs show azimuthal dependence, especially for large SZA and high surface variability
  - Clear-sky daytime LW ADMs consider the solar zenith angle, relative azimuth angle, and surface variability can alter the instantaneous LW flux by up to 10 Wm^{-2}
  - For a given scene type, the mean flux change is less than 1 Wm^{-2} with RMS errors about 2-3 Wm^{-2}
- To build ADMs for NPP, a minimum of one year of RAPS data are needed to ensure that clear-sky scenes are sufficiently sampled