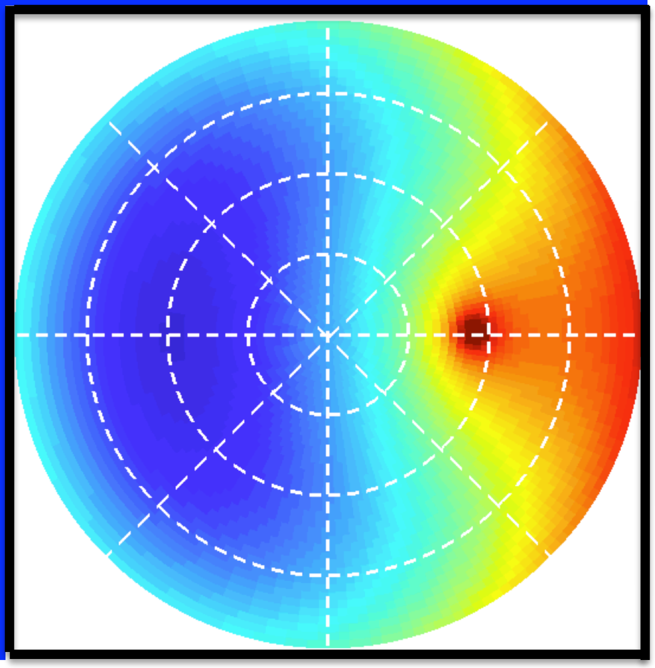
Towards Improved CERES Angular Distribution Models

Wenying Su   Lusheng Liang
Joseph Corbett   Zachary Eitzen
SSAI, Hampton VA

Thanks to Norman Loeb!



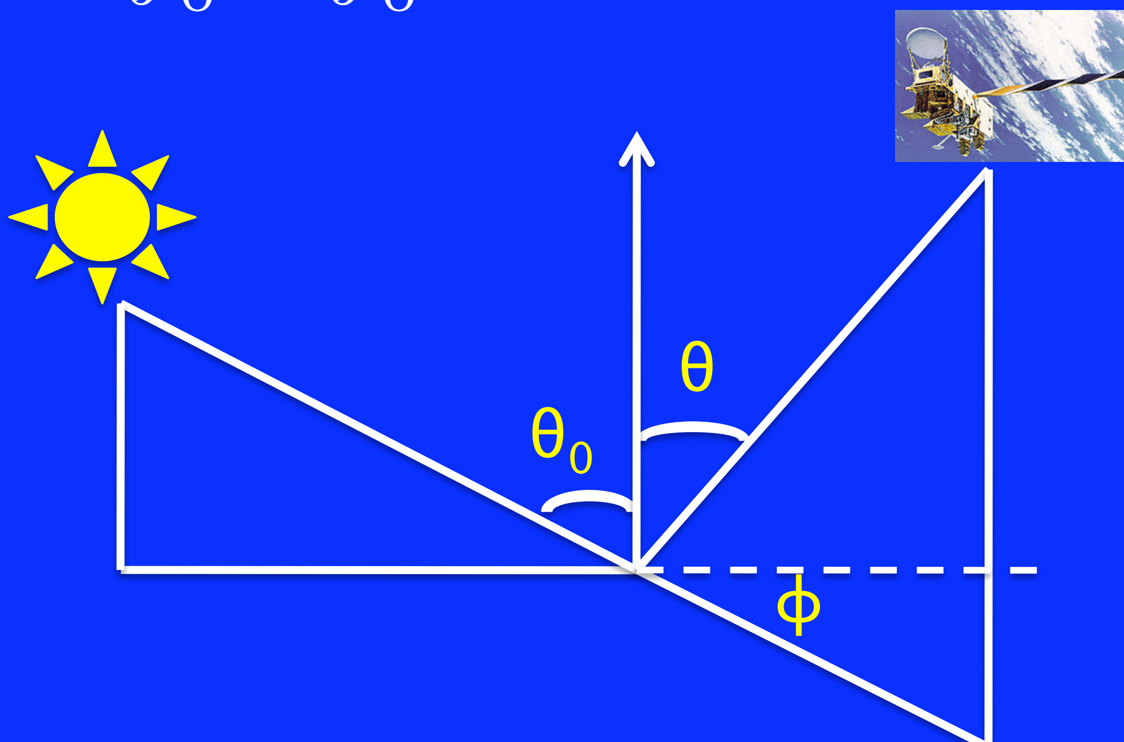
Outline

- Introduction and how to evaluate the angular distribution model (ADM) error;
- Shortwave clear-sky ADM over land/desert, fresh snow;
- Shortwave clear-sky ADM over ocean;
- Shortwave clear-sky ADM over permanent snow and sea ice;
- Longwave daytime cloudy-sky ADM over ocean.

Radiance and flux

- CERES measures radiance: $I(\theta_0, \theta, \phi)$
- Relationship between radiance and flux:

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



The road from radiance to flux: angular distribution model

- Sort observed radiances into angular bins over different scene types;
- Integrate 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:

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

1°

Predicted radiance:

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

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

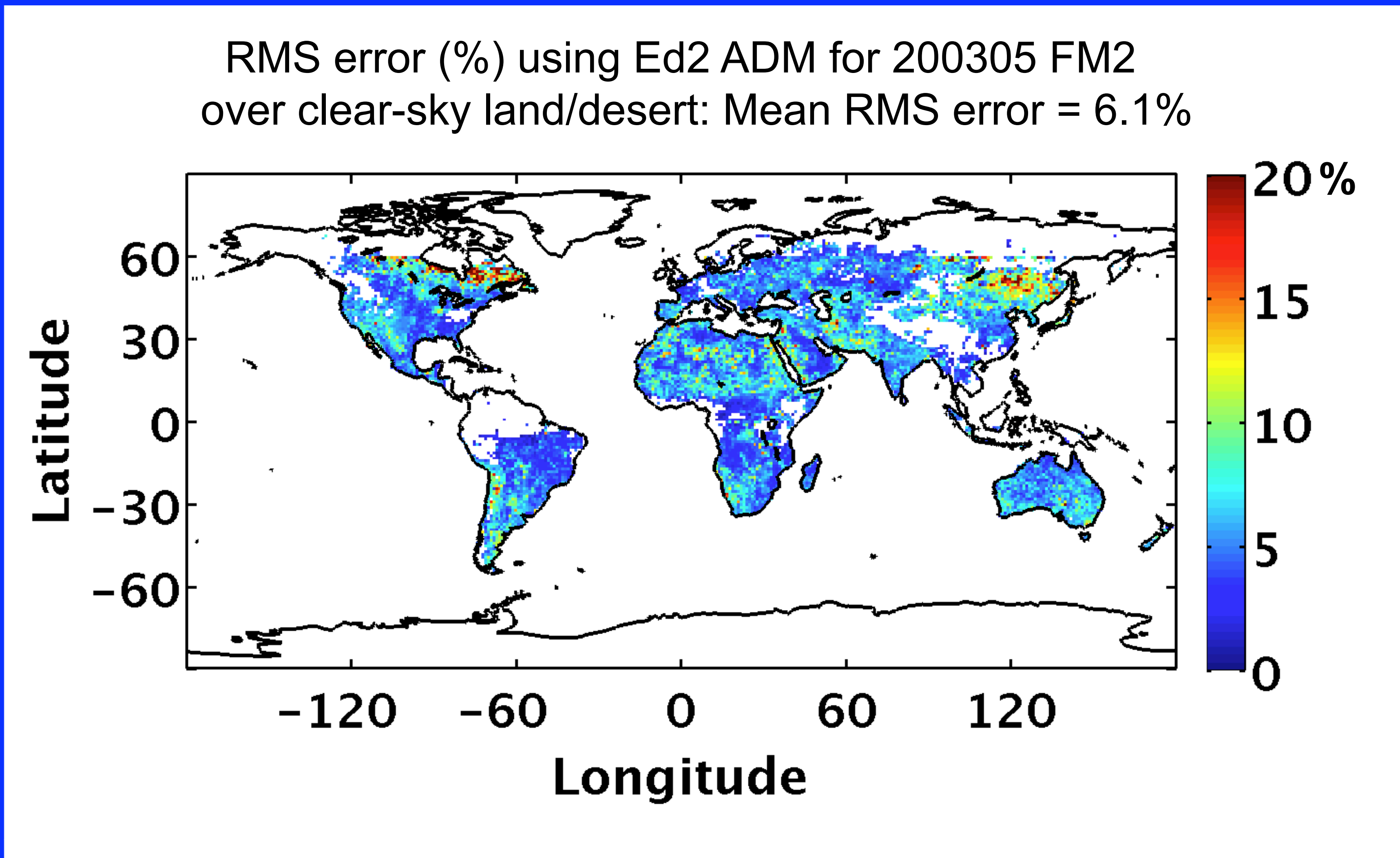
Clear-sky land/desert angular distribution model

- Collect clear-sky CERES reflectance over 1°X1° regions for each month;
- Stratify reflectance within each 1°X1° region by NDVI (0.1) and $\cos\theta_0$ (0.2);
- Apply an 8-parameter fit to produce BRDF and ADM for each NDVI and $\cos\theta_0$ intervals within each 1°X1° region.

$$\rho(\mu_0,\mu,\phi) = \frac{1}{4}\frac{\omega}{\mu+\mu_0}\left\{1-exp\left[-\tau\left(\frac{1}{\mu}+\frac{1}{\mu_0}\right)\right]\right\}\cdot P(\alpha)[1+B(\alpha')]+$$
$$\frac{1}{4}\frac{\omega}{\mu+\mu_0}[H^{(0)}(\mu)H^{(0)}(\mu_0)(1-e(\mu+\mu_0)-b(1-\omega)\mu\mu_0)+$$
$$b(1-\mu^2)^{1/2}\cdot(1-\mu_0^2)^{1/2}H^{(1)}(\mu)H^{(1)}(\mu_0)cos\phi]-$$
$$\frac{1}{4}\frac{\omega}{\mu+\mu_0}P'(\alpha)+\left(d_0+\frac{d_1}{\mu+\mu_0}\right)+r_s(\mu_0,\mu,\phi)$$

From Ahmad & Deering, 1992

Use RMS error between normalized predicted and measured radiance to test the ADM

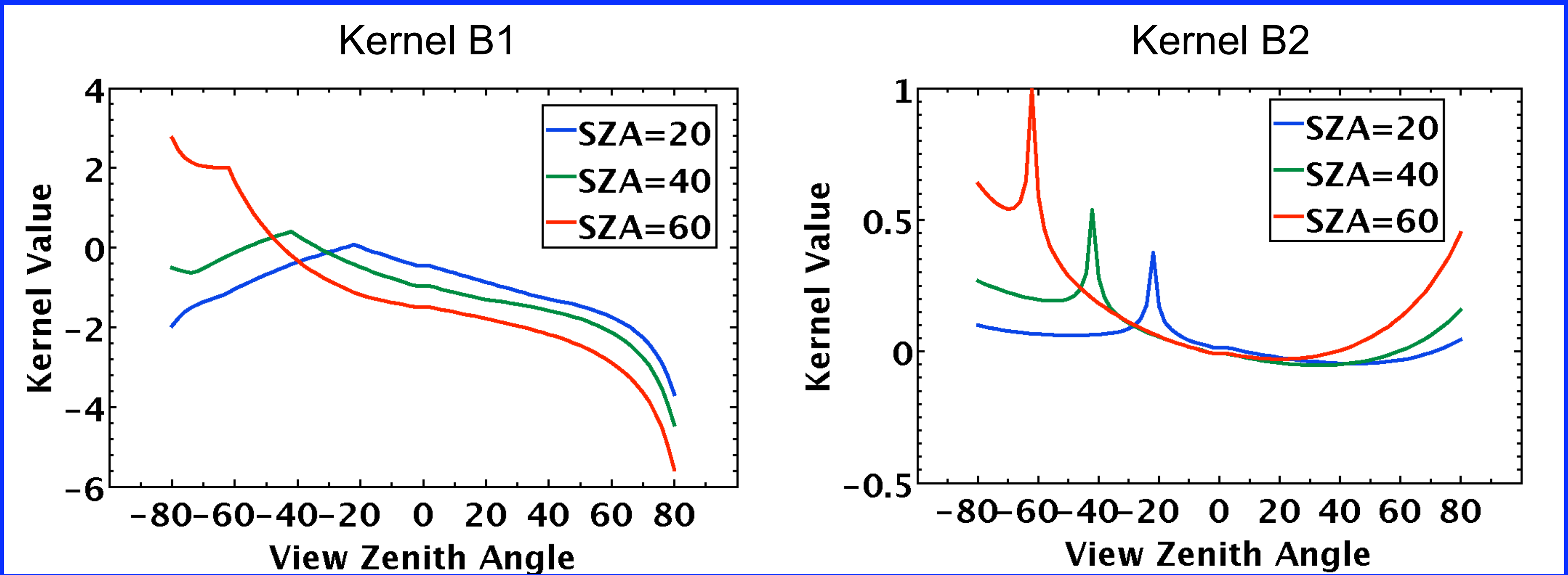


A simpler BRDF model: Modified RossLi

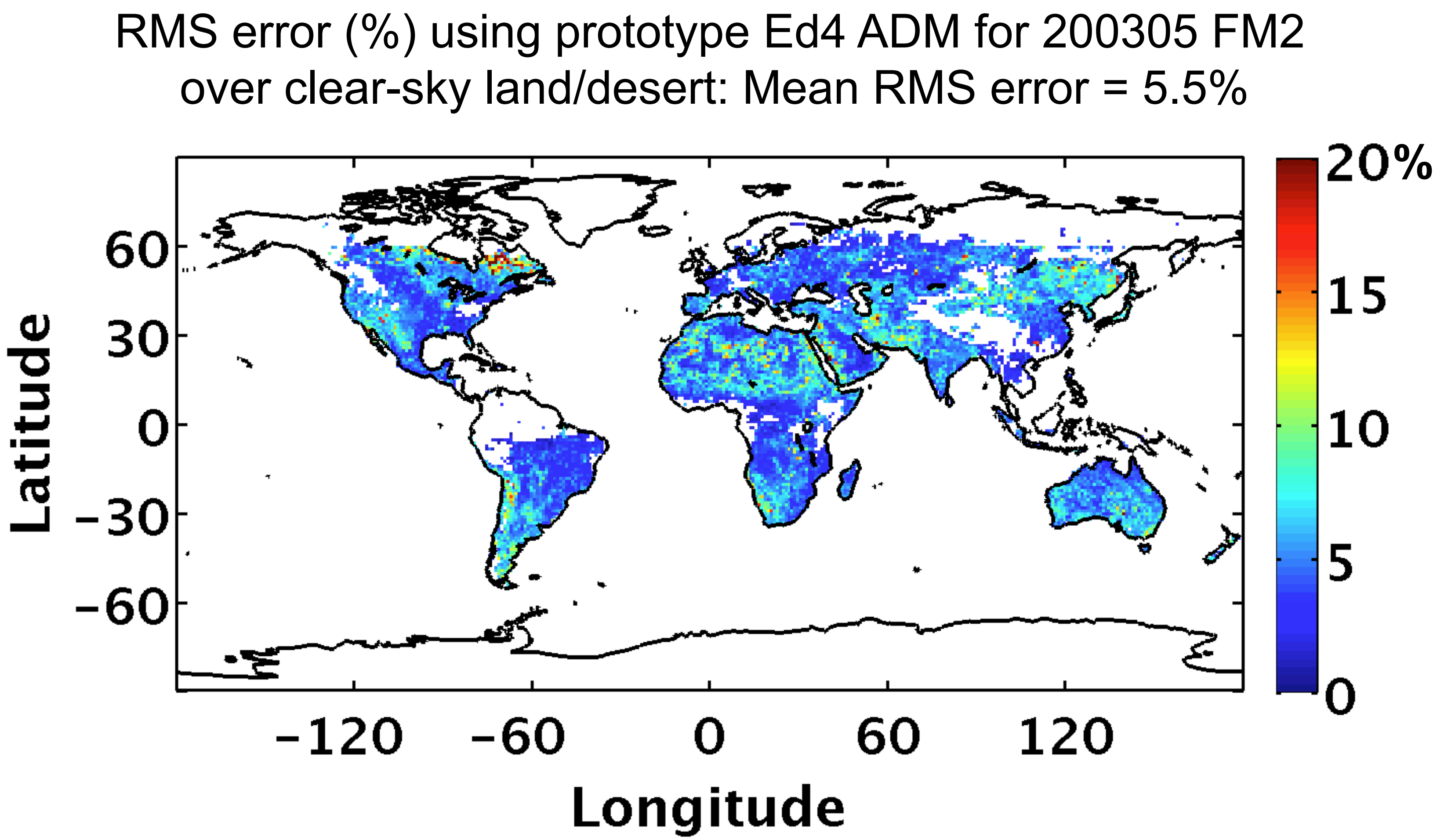
- B1 estimates the directional reflectance of a flat surface with randomly distributed and oriented protrusions;
- B2 approximates the radiative transfer within a vegetation canopy, accounts for the hot spot effect;

$$\rho(\mu_0, \mu, \phi) = k_0 + k_1 \cdot B_1(\mu_0, \mu, \phi) + k_2 \cdot B_2(\mu_0, \mu, \phi)$$

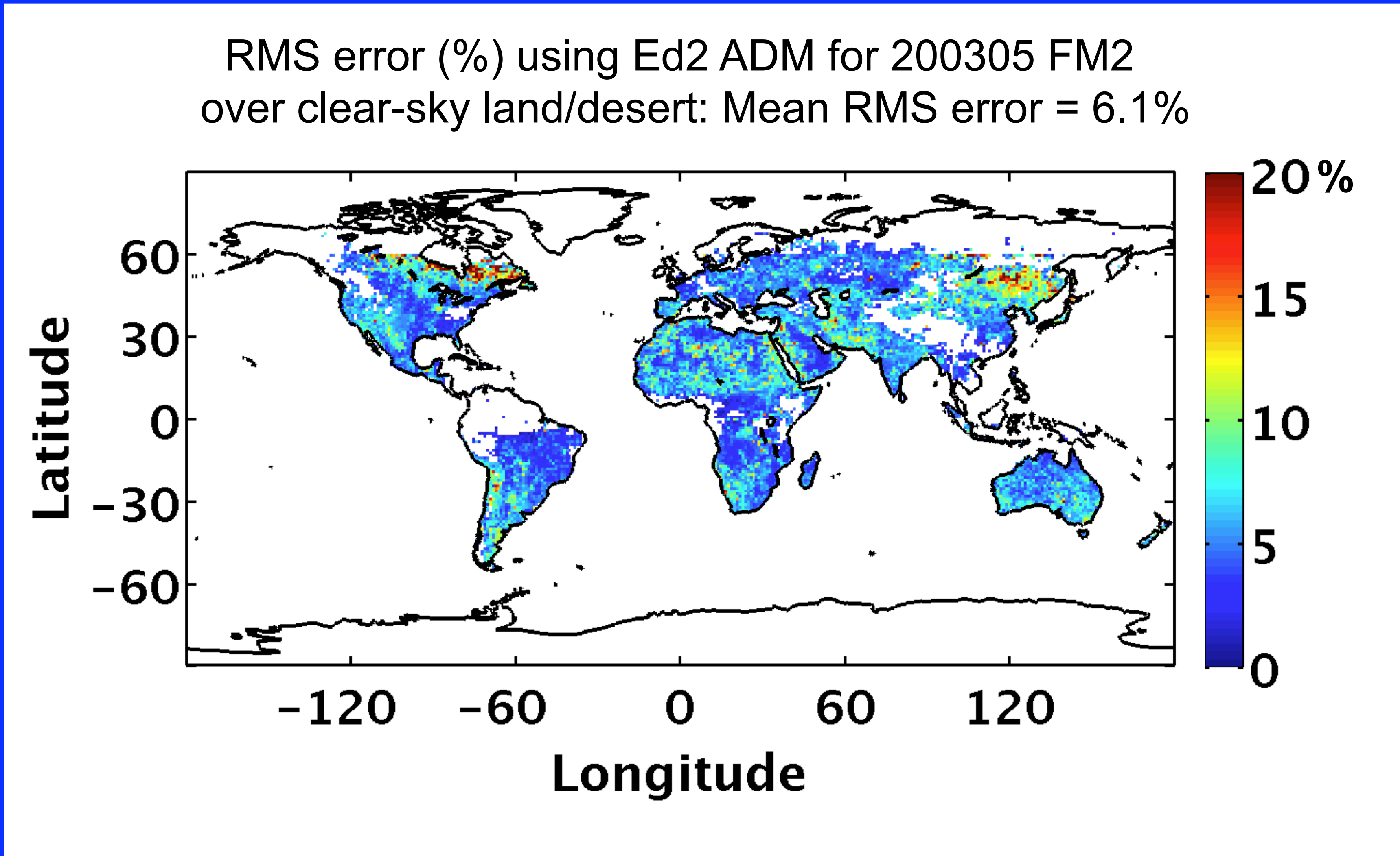
from Maignan et al., 2004



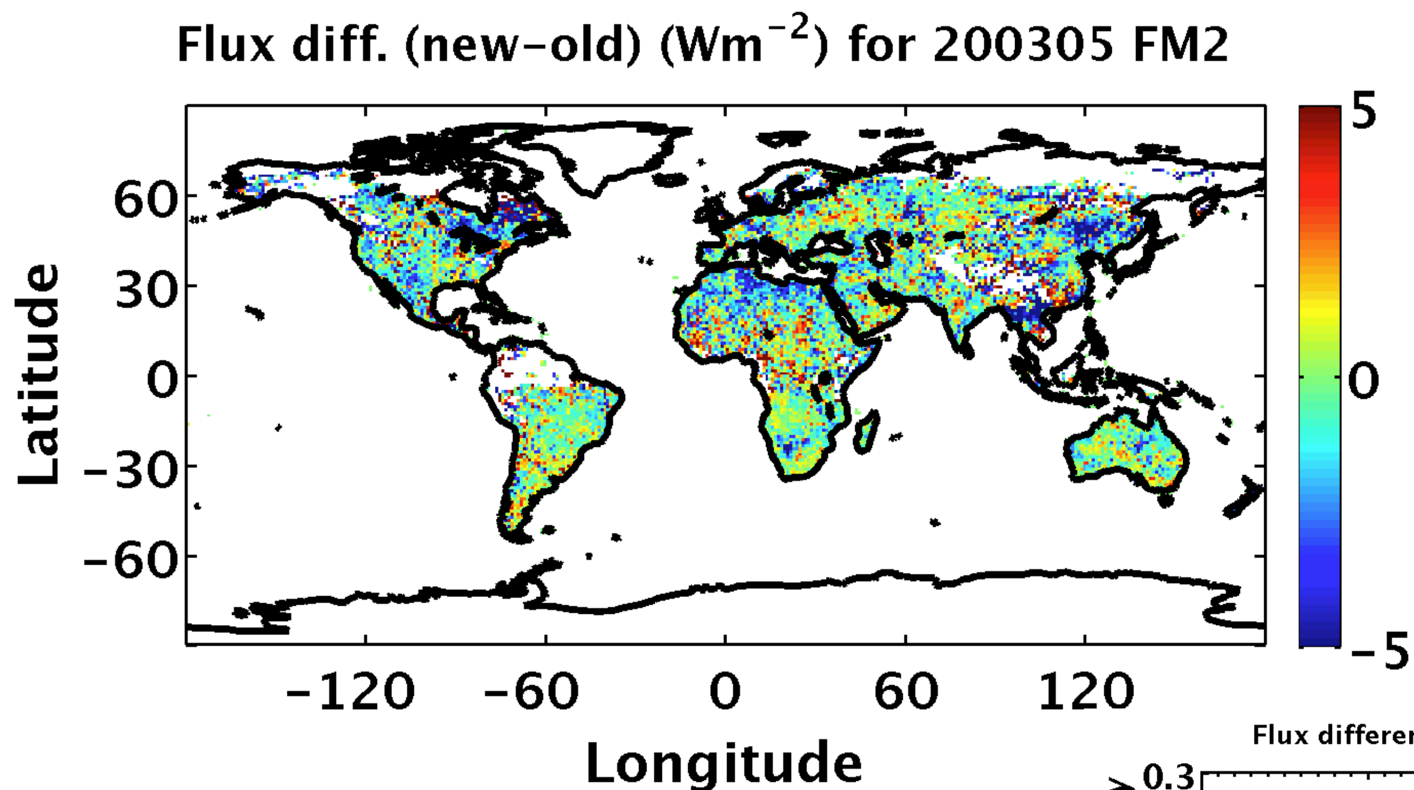
The new BRDF model reduces the RMS error

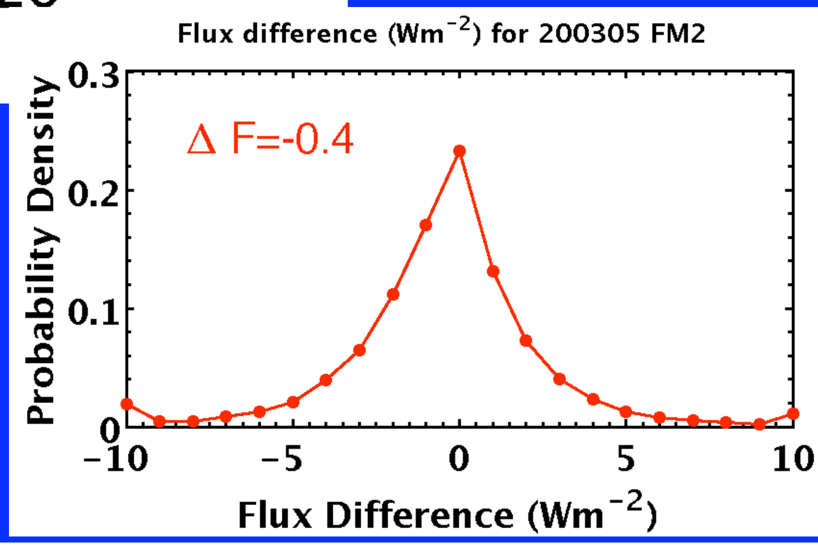


The new BRDF model reduces the RMS error



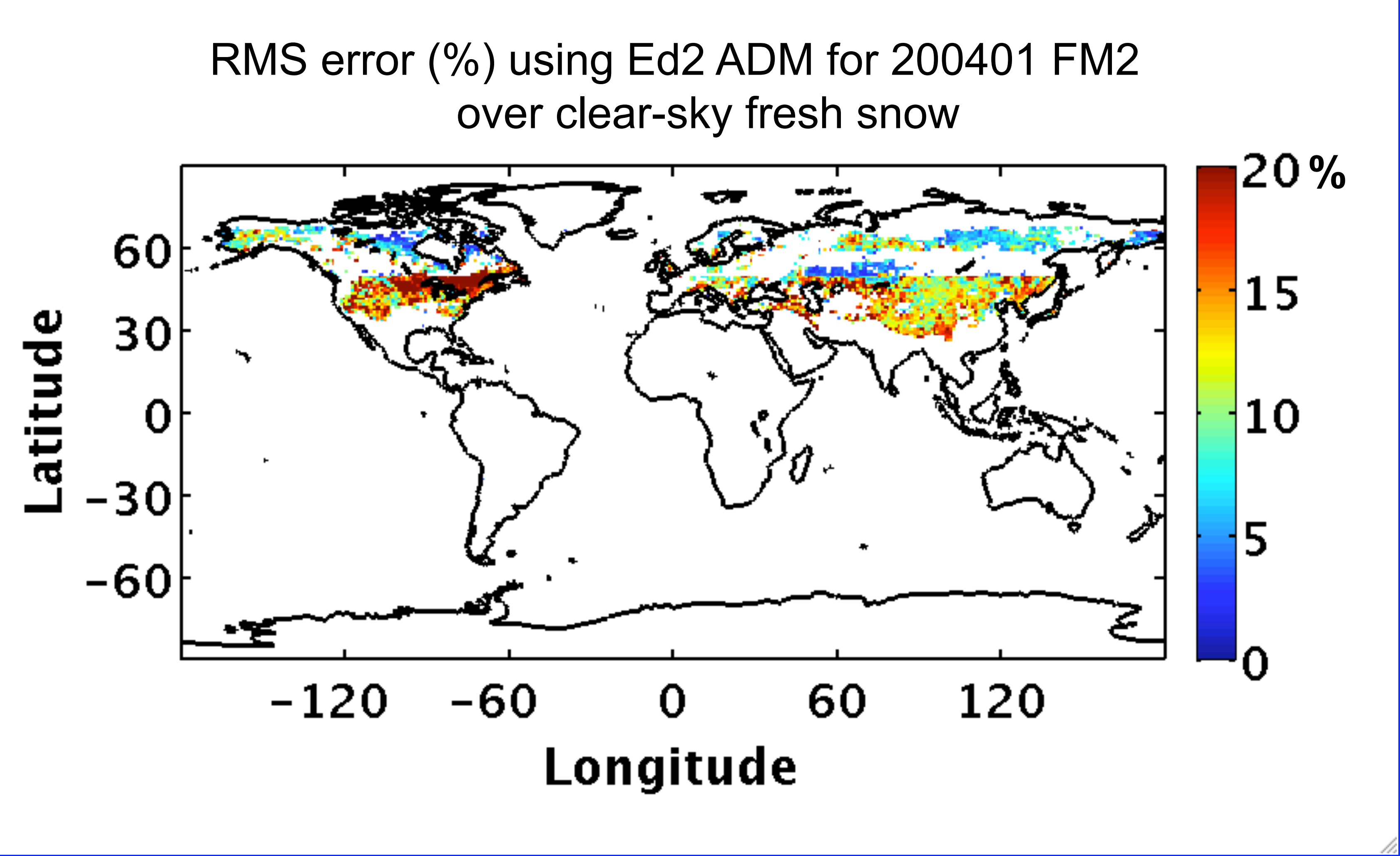
New BRDF model reduces the instantaneous TOA flux by 0.4 Wm^{-2}





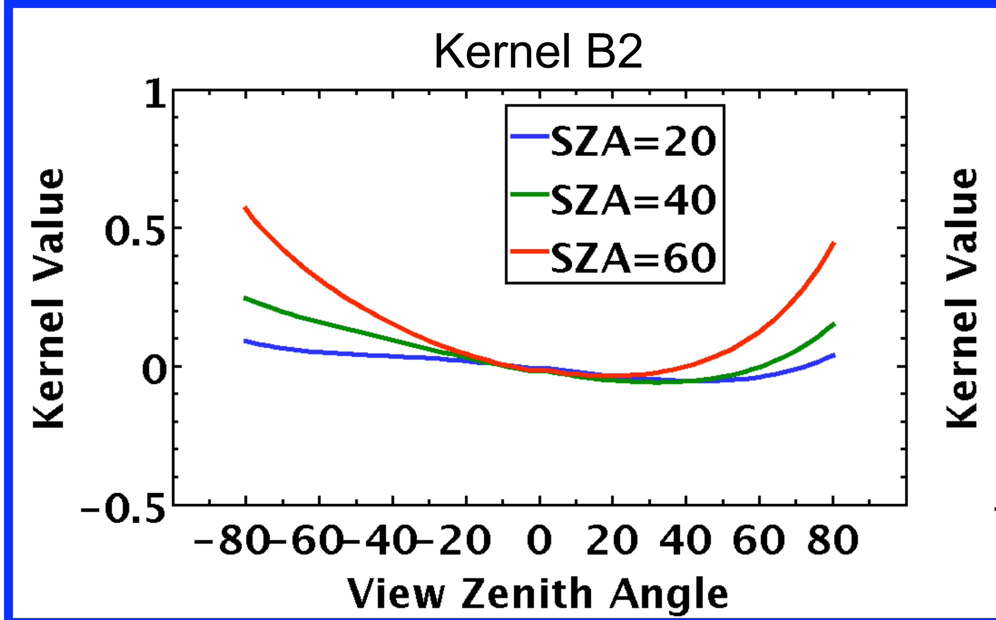
Original clear-sky fresh snow ADM

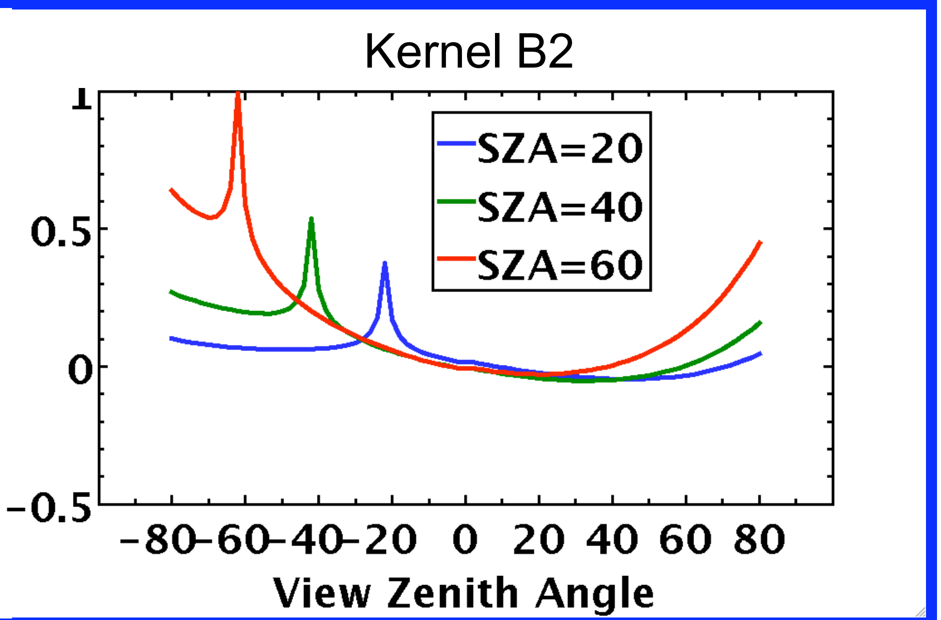
- Under clear-sky, fresh snow ADM considers snow fraction and surface brightness (only for 99~100% snow fraction)



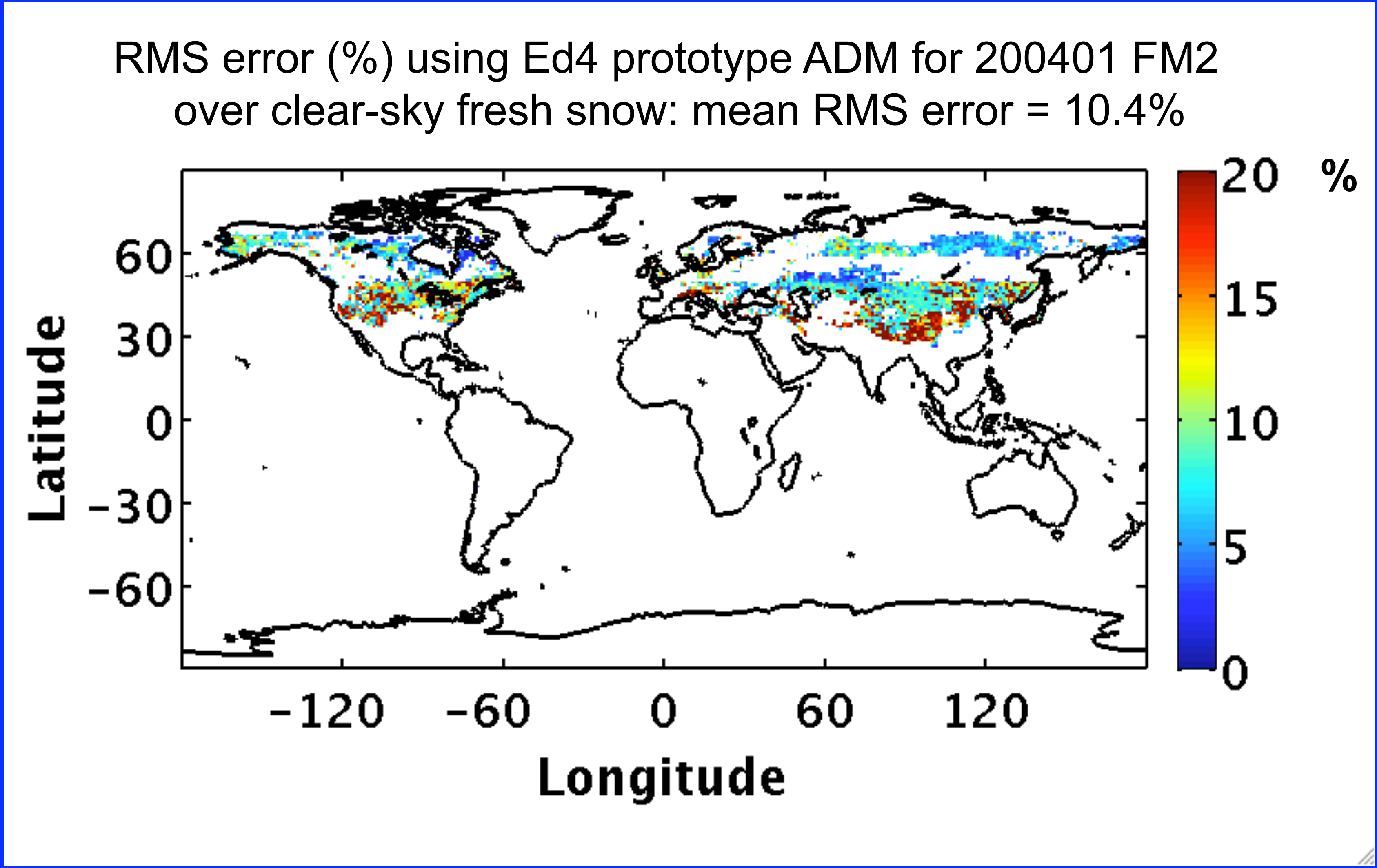
New clear-Sky fresh snow ADM: RossLi

- Collect CERES fresh snow reflectance over 1°X1° regions for each seasonal month;
- Stratify reflectance within each 1°X1° region by NDVI (0.1) and $\cos\theta_0$ (0.2);
- Apply the RossLi fit to produce BRDF and ADM for each NDVI and $\cos\theta_0$ intervals within each 1°X1° region.

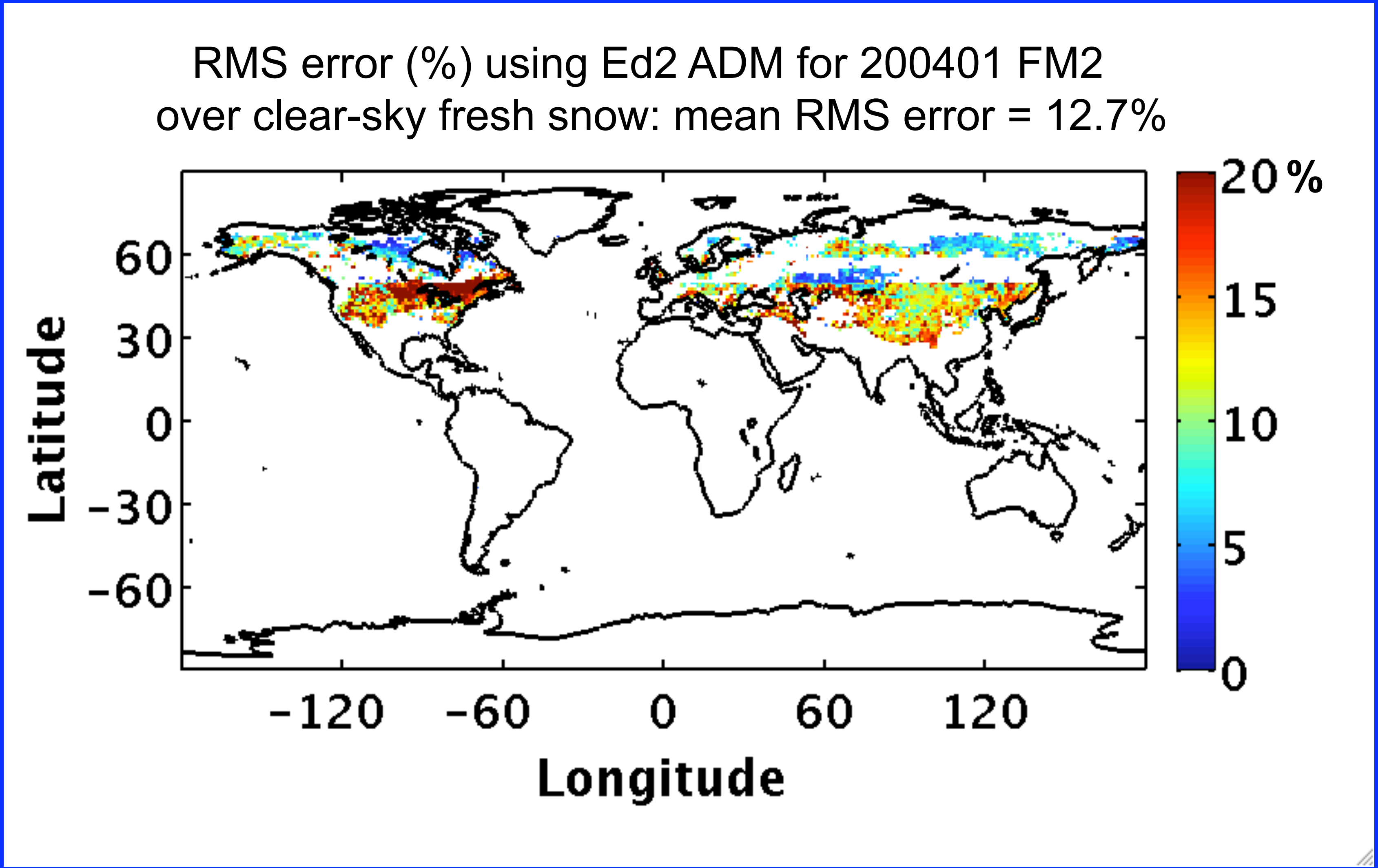




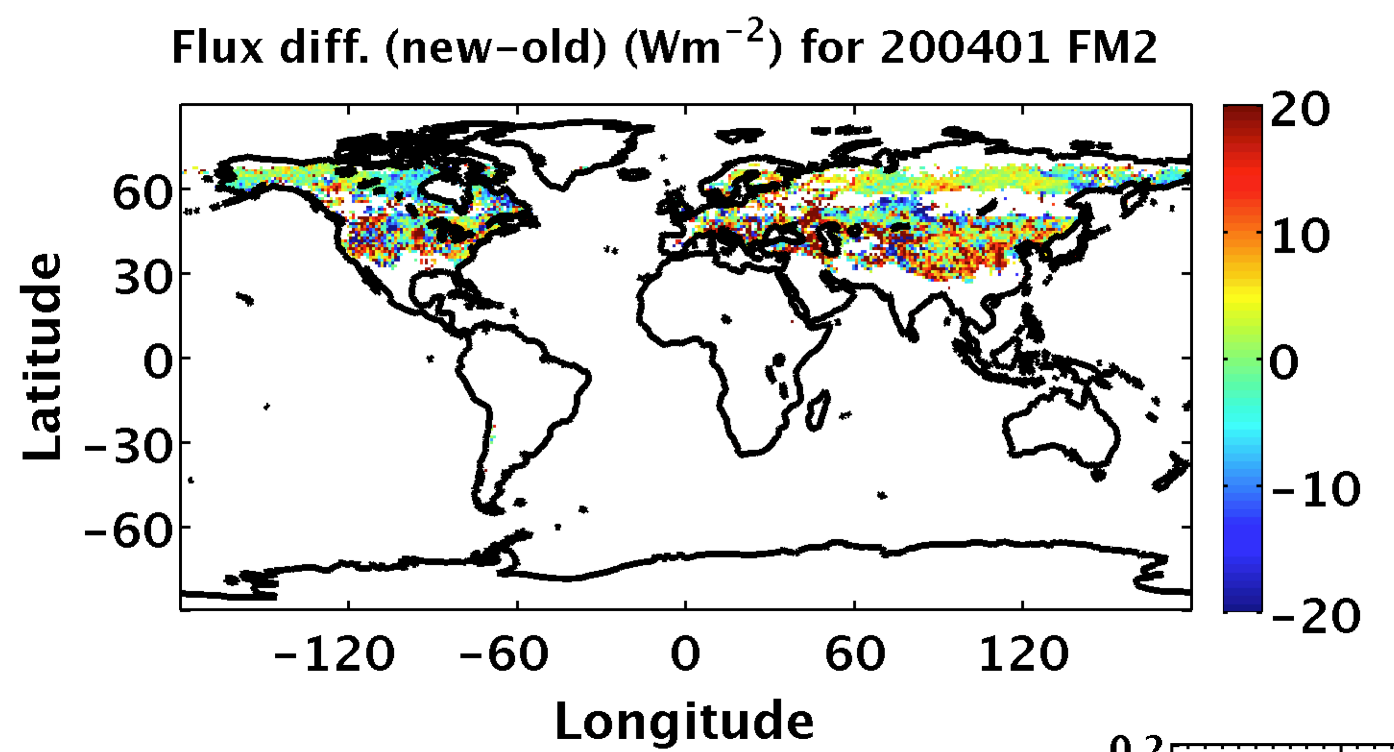
RossLi model reduces the RMS over fresh snow

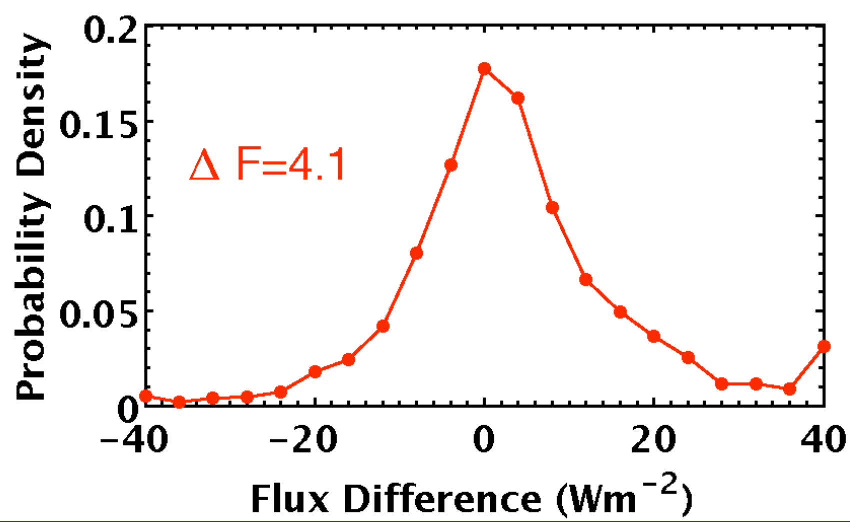


RossLi model reduces the RMS over fresh snow



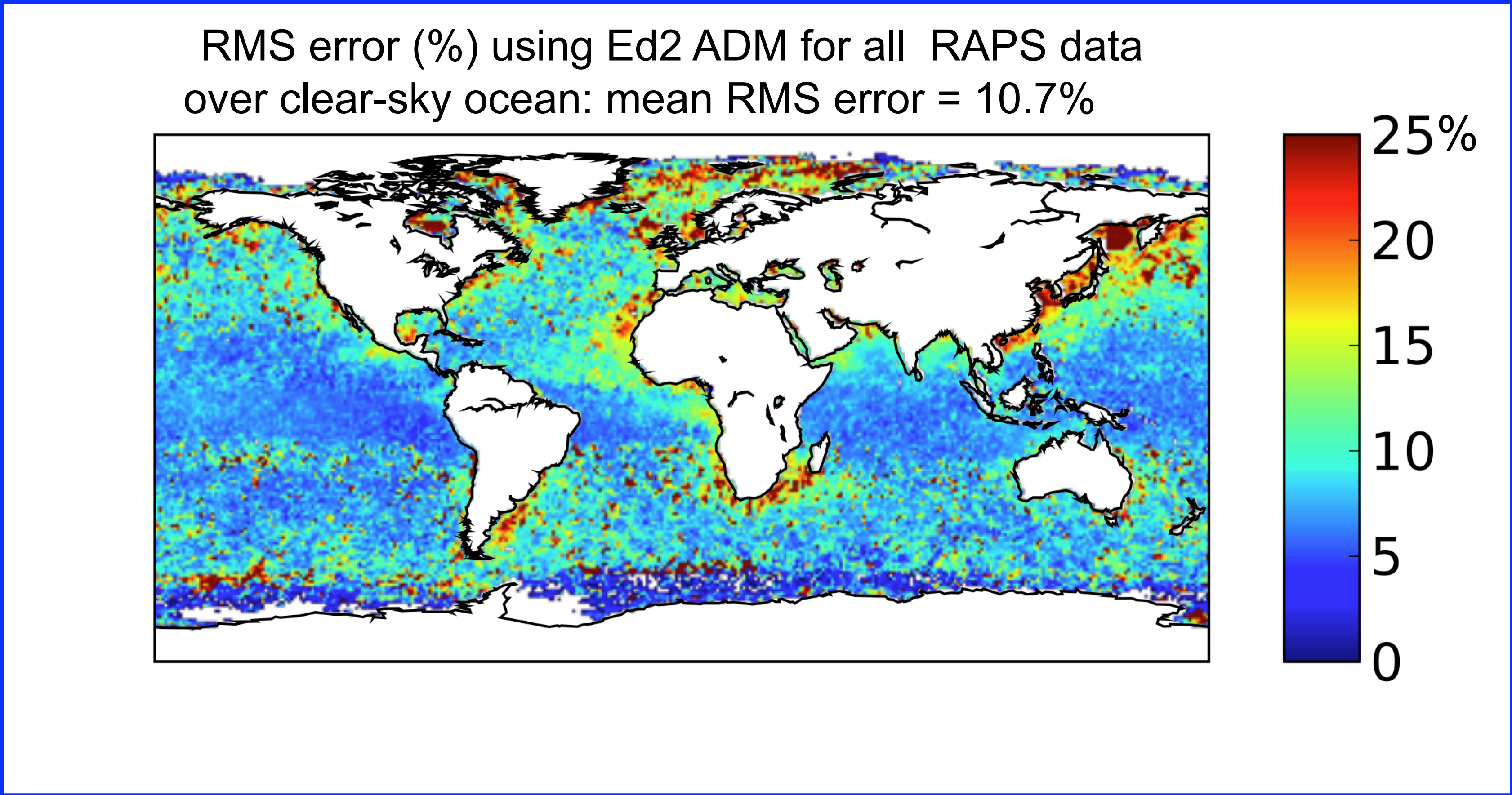
New fresh snow ADM increases the instantaneous TOA flux by 4.1 Wm^{-2}





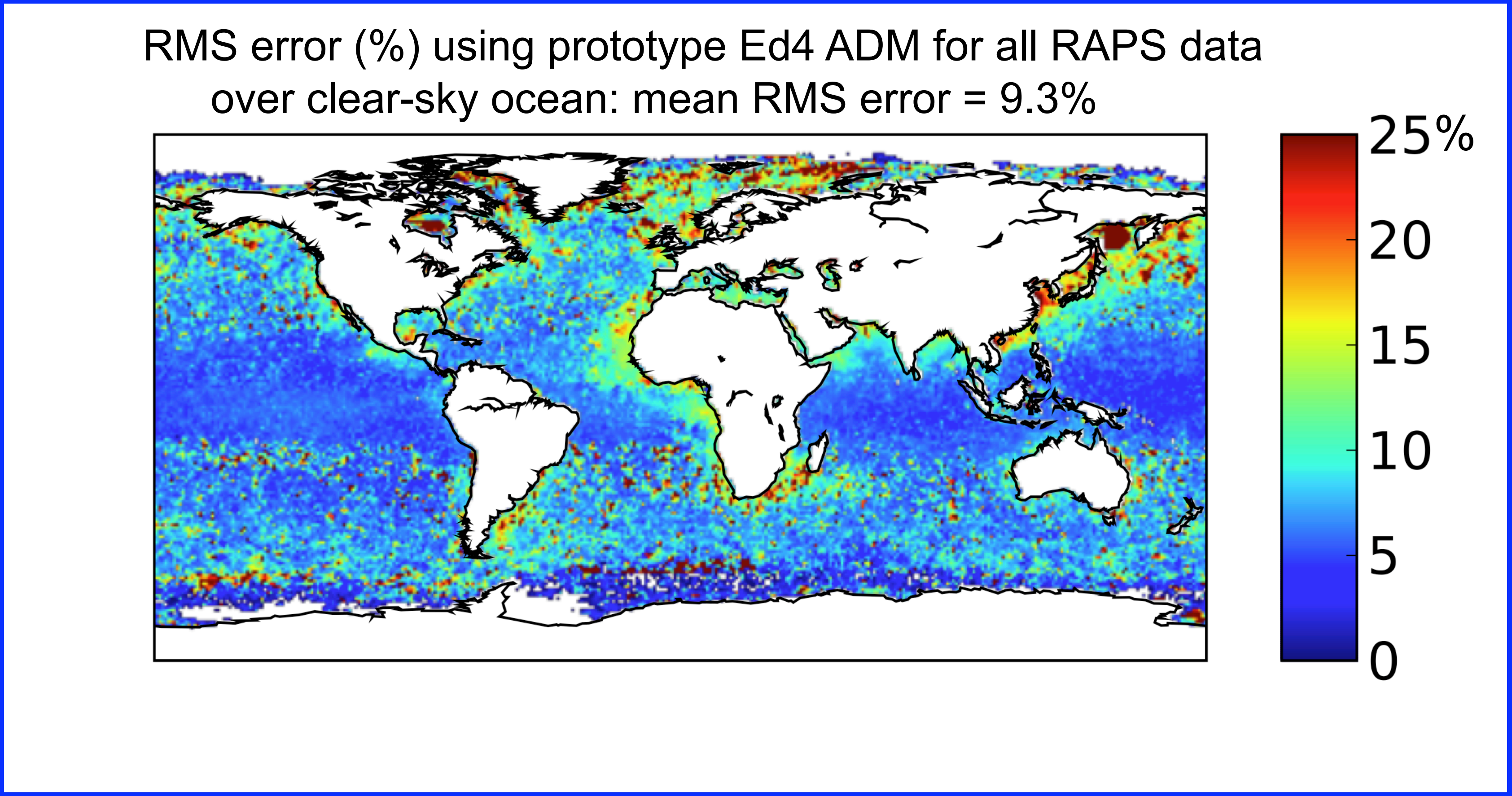
Clear-sky angular distribution model over ocean

- Clear-sky ADM over ocean $R(w, \theta_0, \theta, \phi)$;
- Aerosol optical depth was not directly considered, ADM dependence on aerosol optical depth is implicitly accounted for by theoretical adjustment.

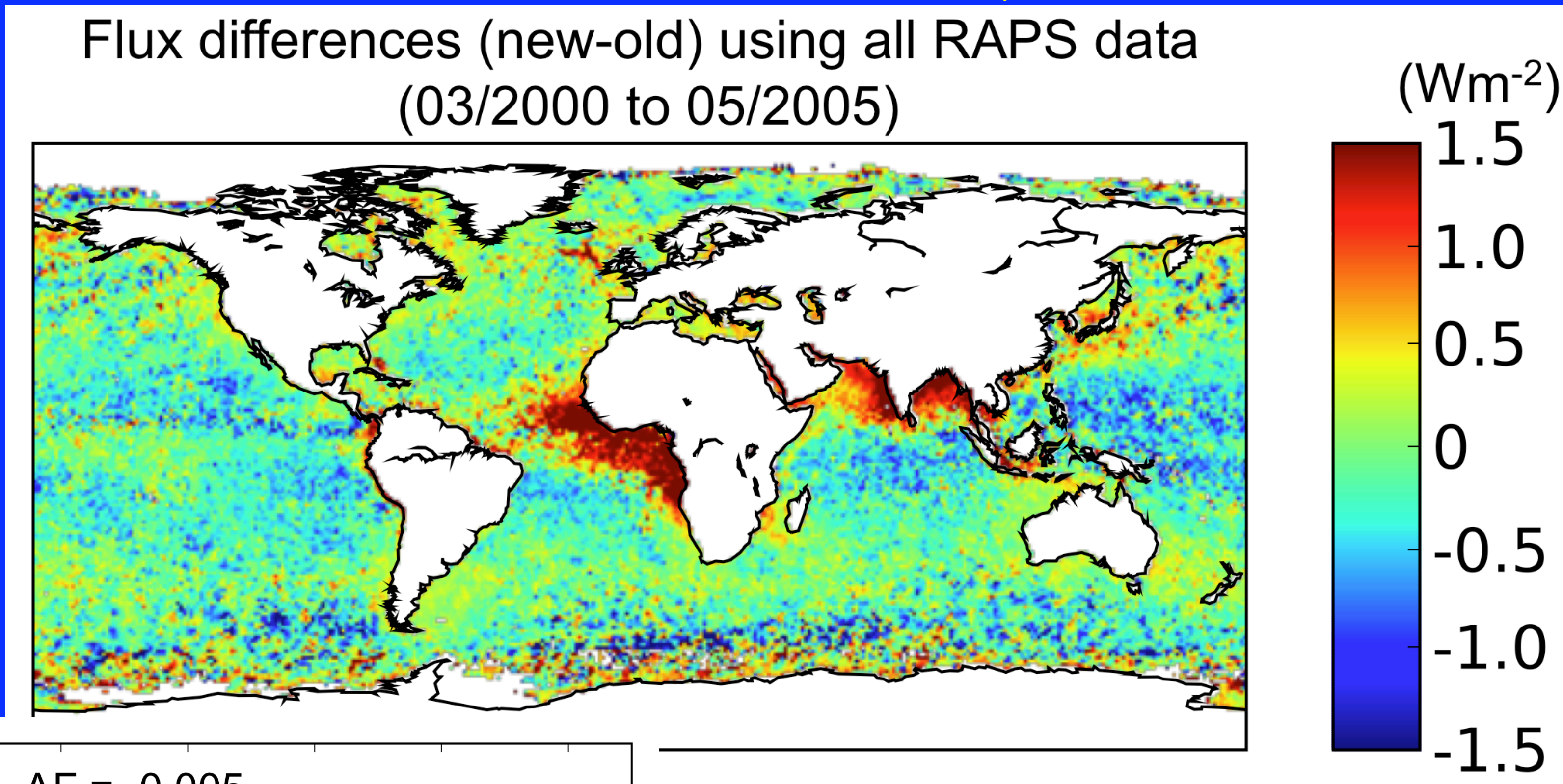


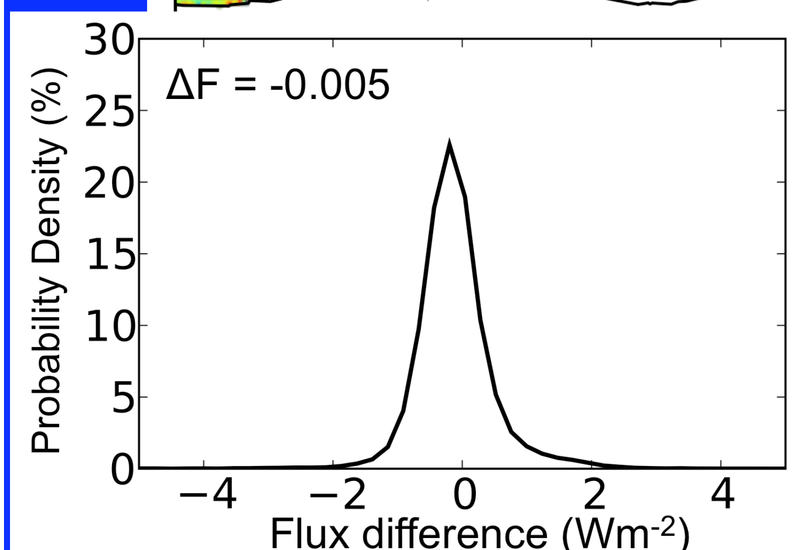
New clear-sky ADM over ocean accounts for AOD

- Develop a two-band (0.64 and 0.86 μm) AOD retrieval;
- Stratify AOD into low and high bins;
- Build ADM for low and high AOD bin separately.



New clear-sky ocean ADM decreases the instantaneous TOA flux by 0.005 Wm^{-2}



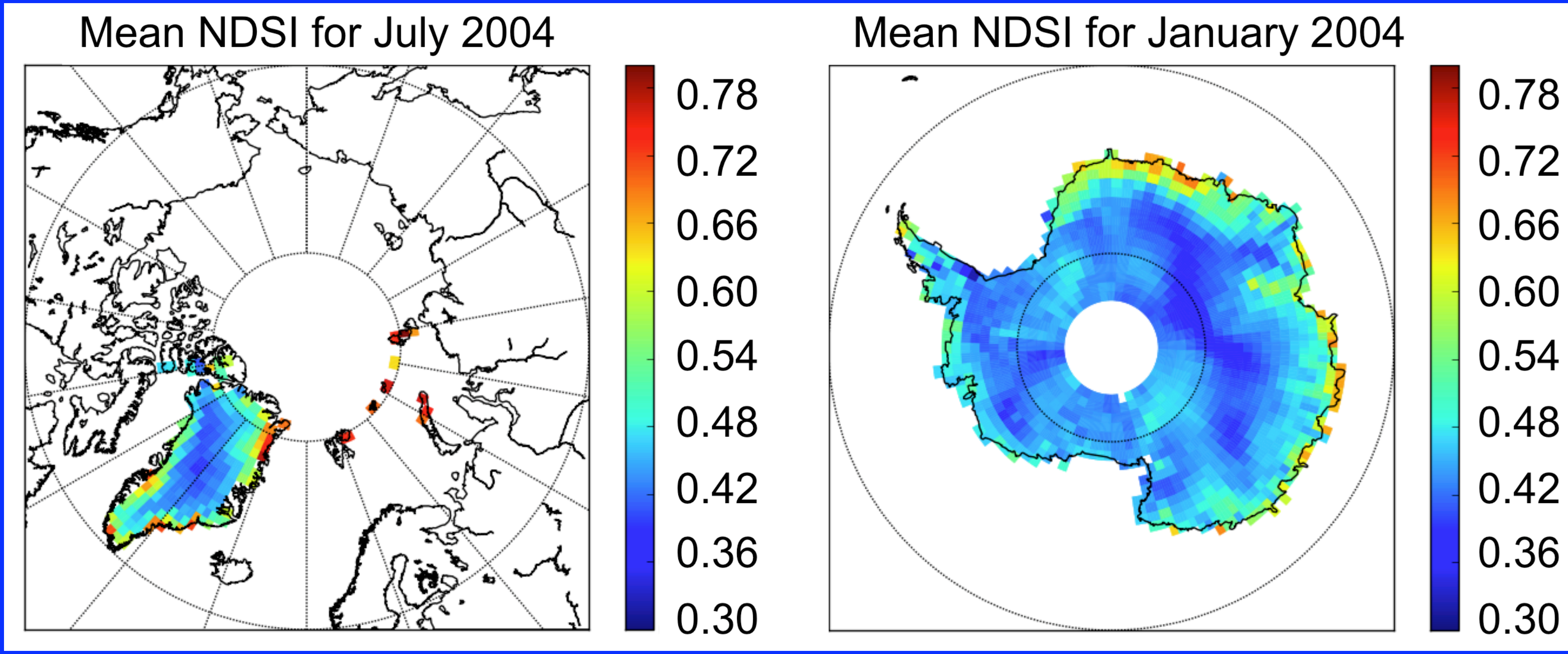


Clear-sky ADM over permanent snow

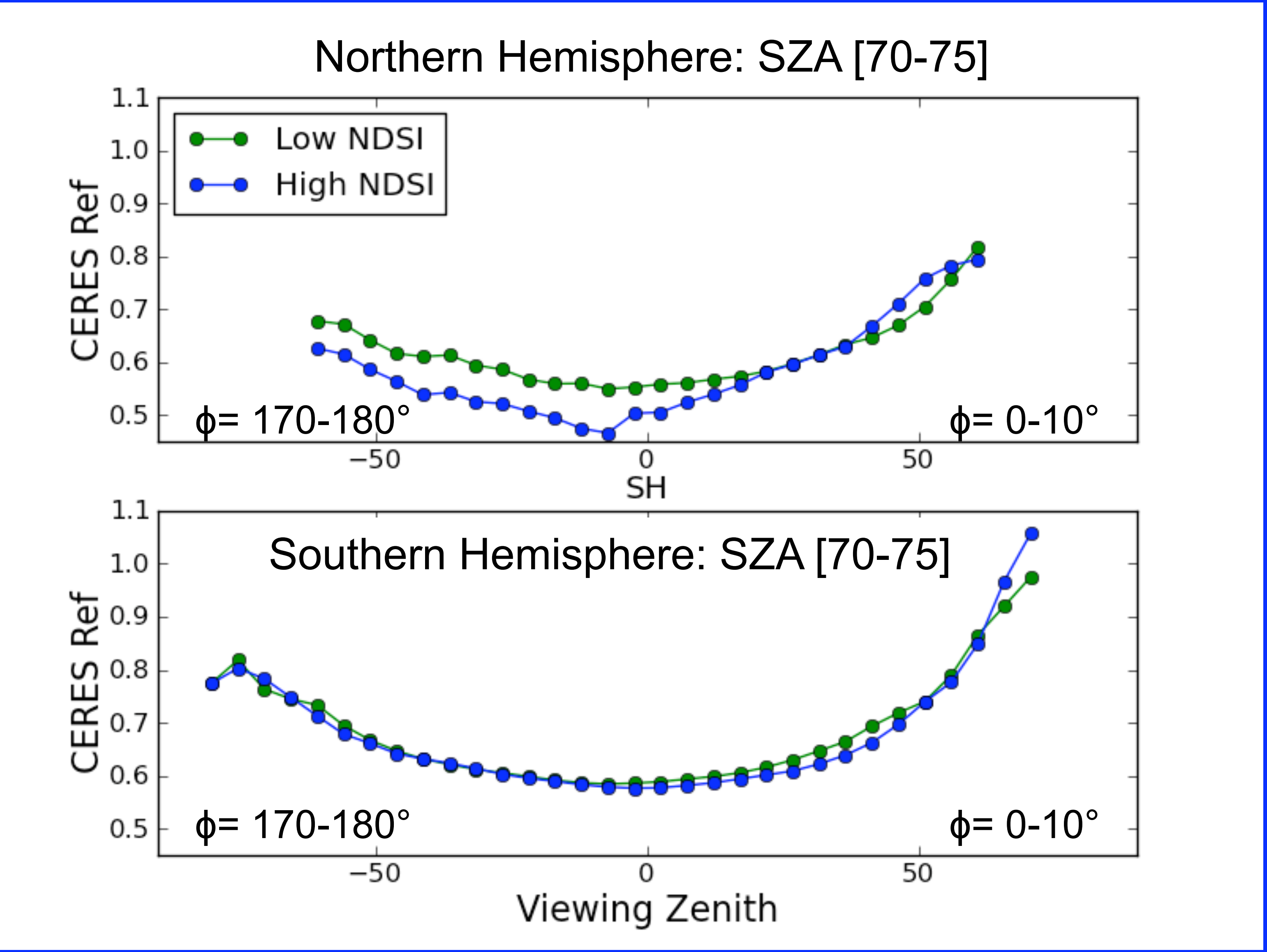
- Use normalized snow index (NDSI) to classify the anisotropy for permanent snow scenes;

$$NDSI = \frac{\rho_{0.55} - \rho_{1.24}}{\rho_{0.55} + \rho_{1.24}}$$

- NDSI is higher in coastal areas where snow grain size is larger.



Reflectance over permanent snow is sensitive to NDSI in northern hemisphere but not in southern hemisphere

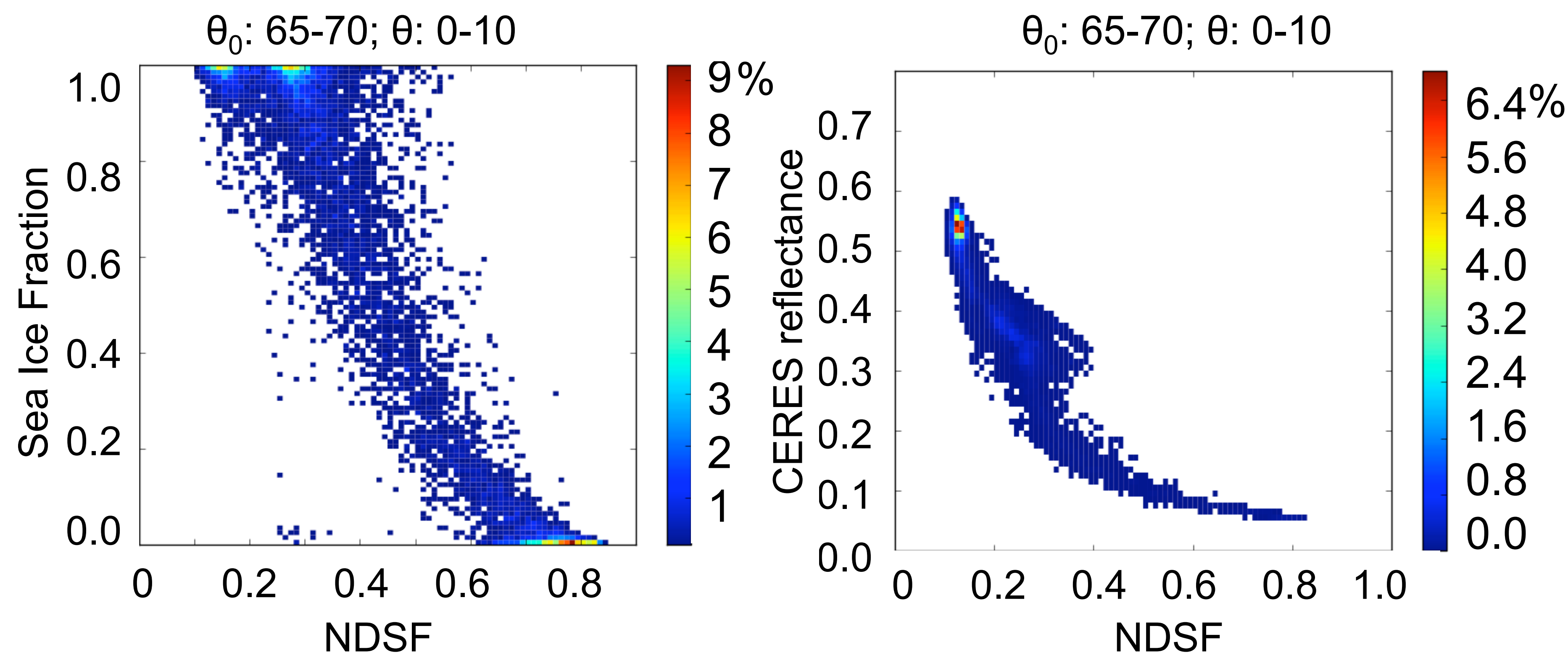


Clear-sky ADM over sea ice

- Use normalized sea ice index (NDSF) to classify the anisotropy for sea ice scenes;

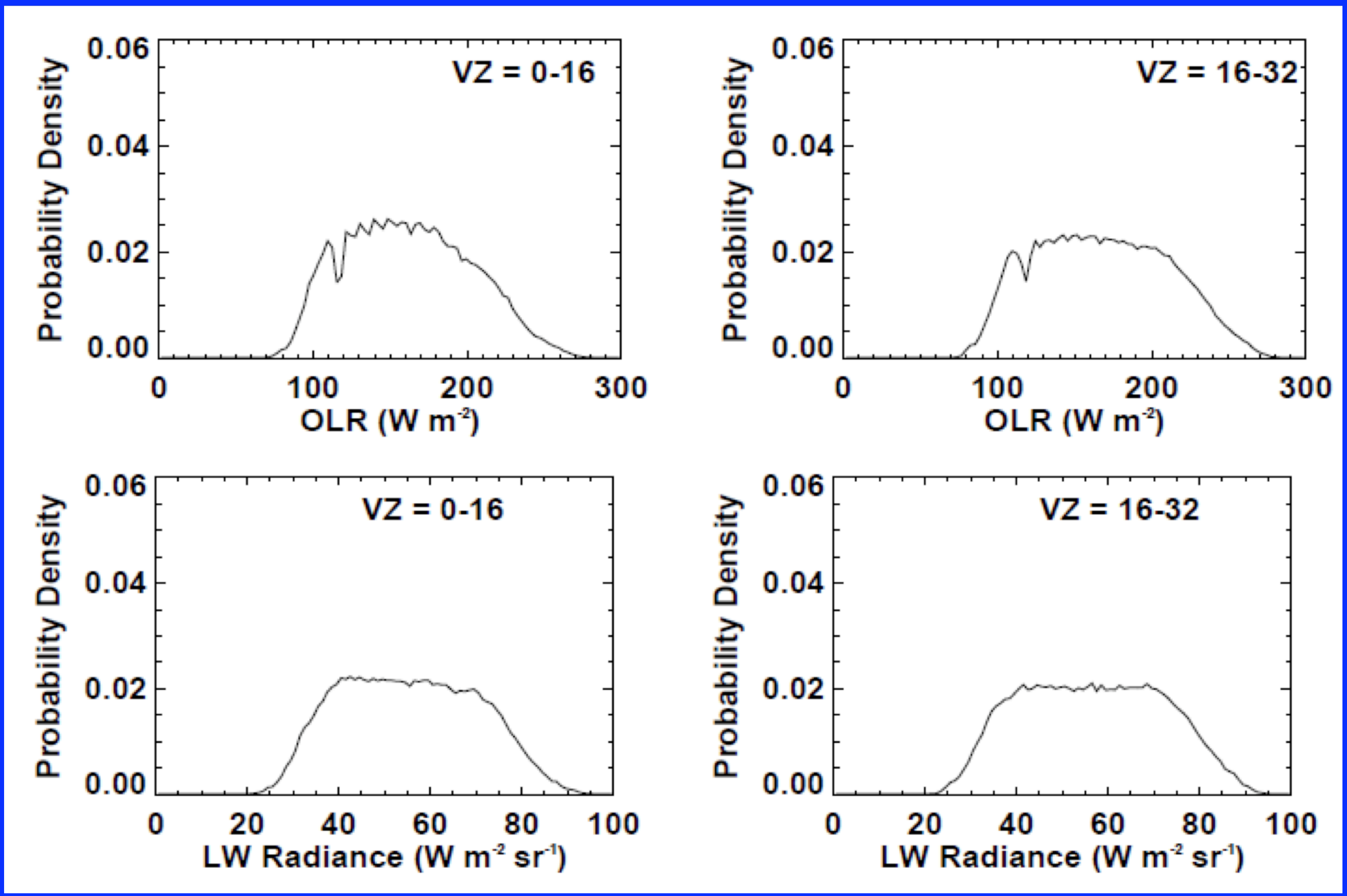
$$NDSF = \frac{\rho_{0.469} - \rho_{0.858}}{\rho_{0.469} + \rho_{0.858}}$$

- NDSF increases as sea ice fraction decreases.



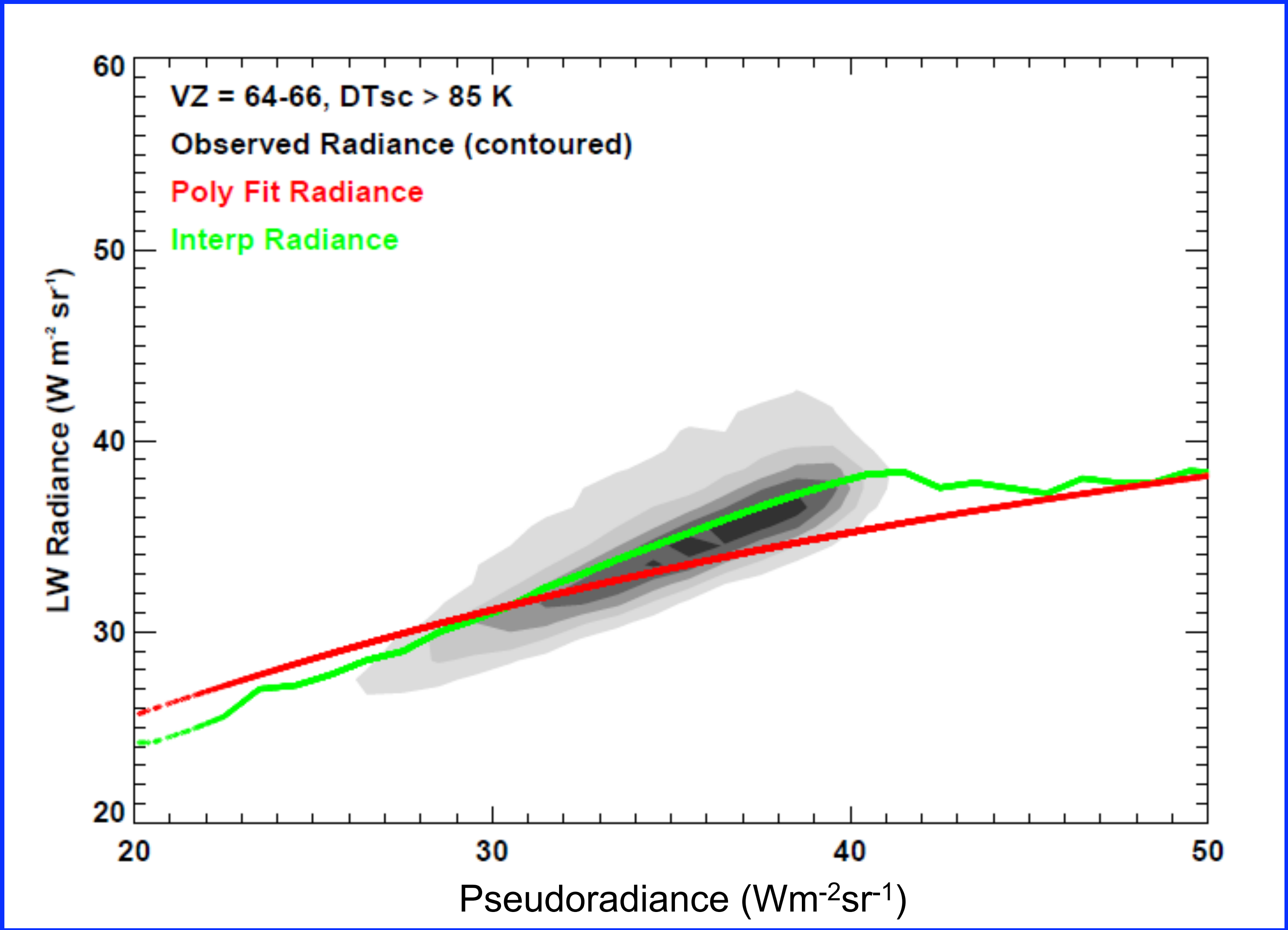
LW ADM for cloudy-sky over the ocean

- For overcast maritime clouds, a dip in OLR appears around 115 Wm^{-2}, but there is no dip in the corresponding LW radiance.

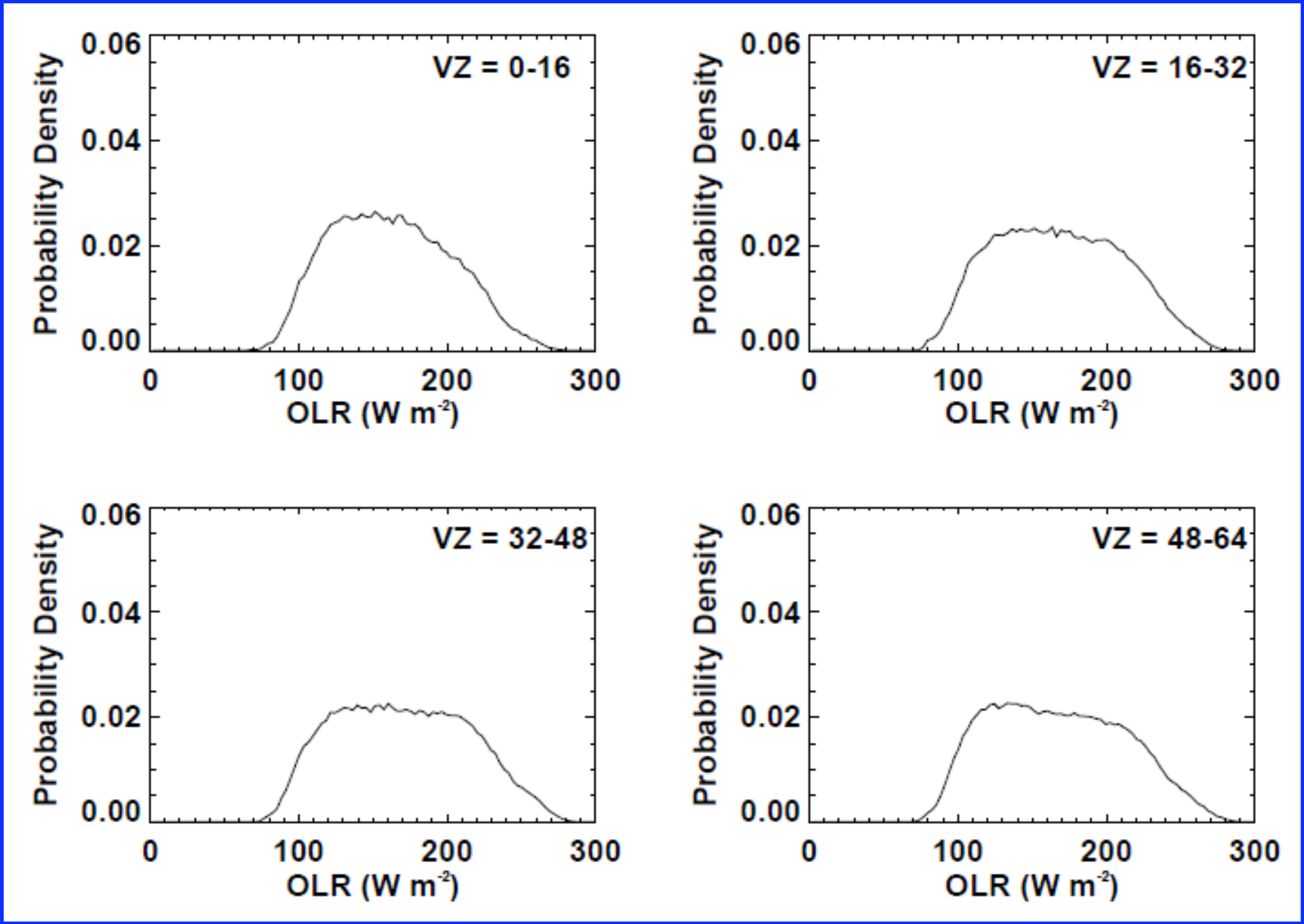


Interpolation

- The third-order polynomial fit between LW radiance and 'pseudoradiance' was replaced with interpolation scheme



OLR no longer shows the dip using the modified cloudy-sky LW ADM



More talks on ADM

Co-I talk by Lusheng Liang on Thursday
"Progress in CERES Clear-sky Aerosol Optical Thickness Dependent Angular Distribution Model over Ocean"

Working group talk by Zach Eitzen
"Progress in Longwave ADMs for Cloudy Skies over the Ocean"

Working group talk by Joe Corbett
"Use of MODIS spectral bands to classify snow and sea ice anisotropy for TOA angular models"

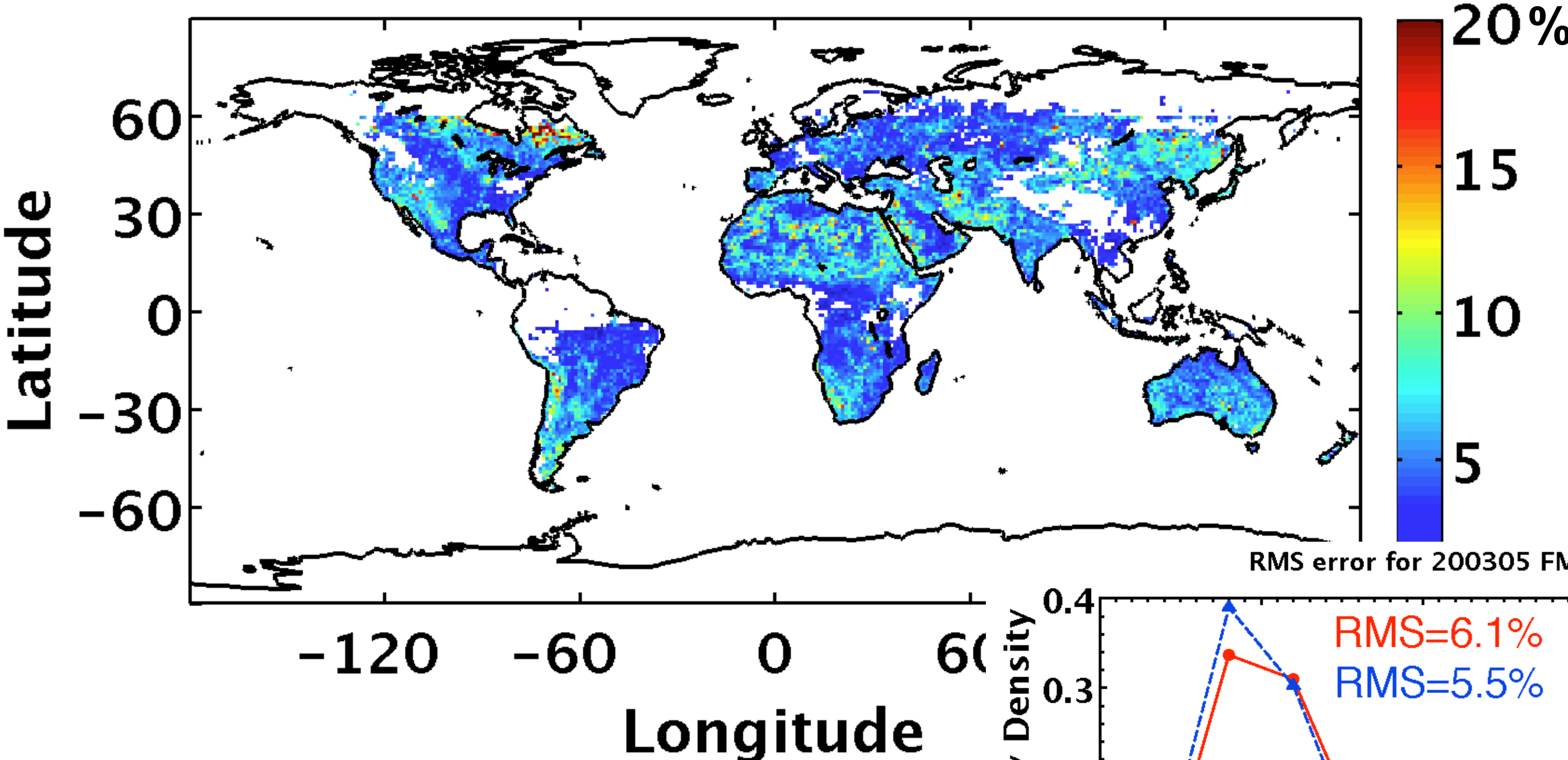
Summary

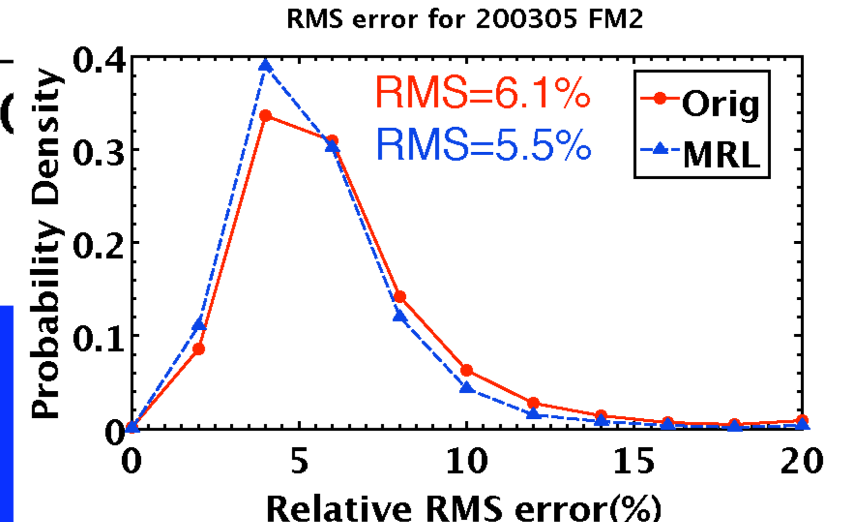
- New clear-sky land and desert ADMs, and the fresh snow ADMs reduce the RMS error between normalized predicted and observed radiances;
- Aerosol optical depth classified clear ocean ADMs reduce the RMS error between predicted and observed radiances over high aerosol loading regions;
- Normalized snow index and sea ice index can potentially be used to classify the anisotropy for permanent snow and sea ice scenes;
- Interpolation scheme adopted for the LW cloudy-sky ADMs eliminates the dip in OLR around 115 Wm^{-2}.

Back up

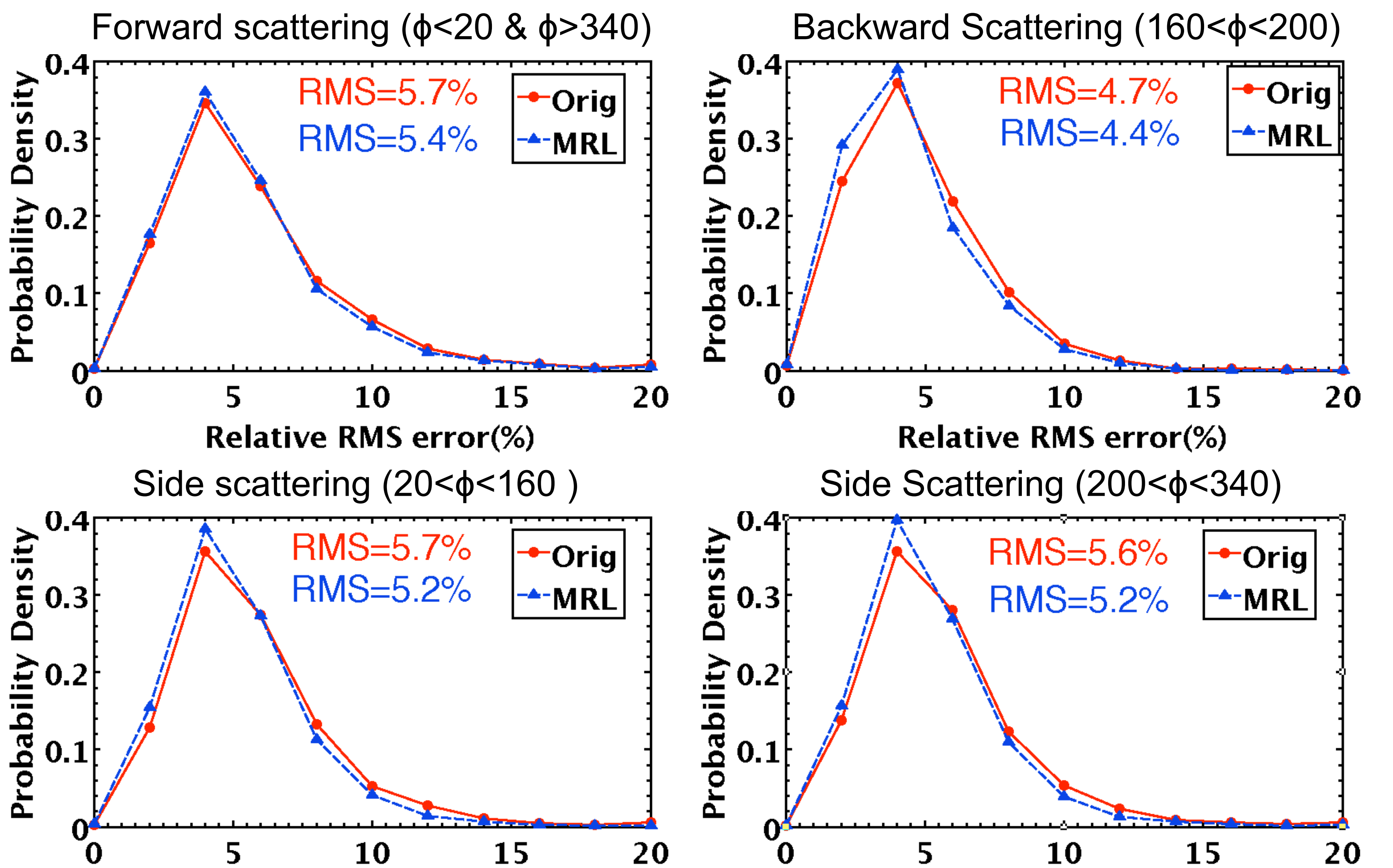
The new BRDF model reduces the RMS error

RMS error (%) using prototype Ed4 ADM for 200305 FM2
over clear-sky land/desert



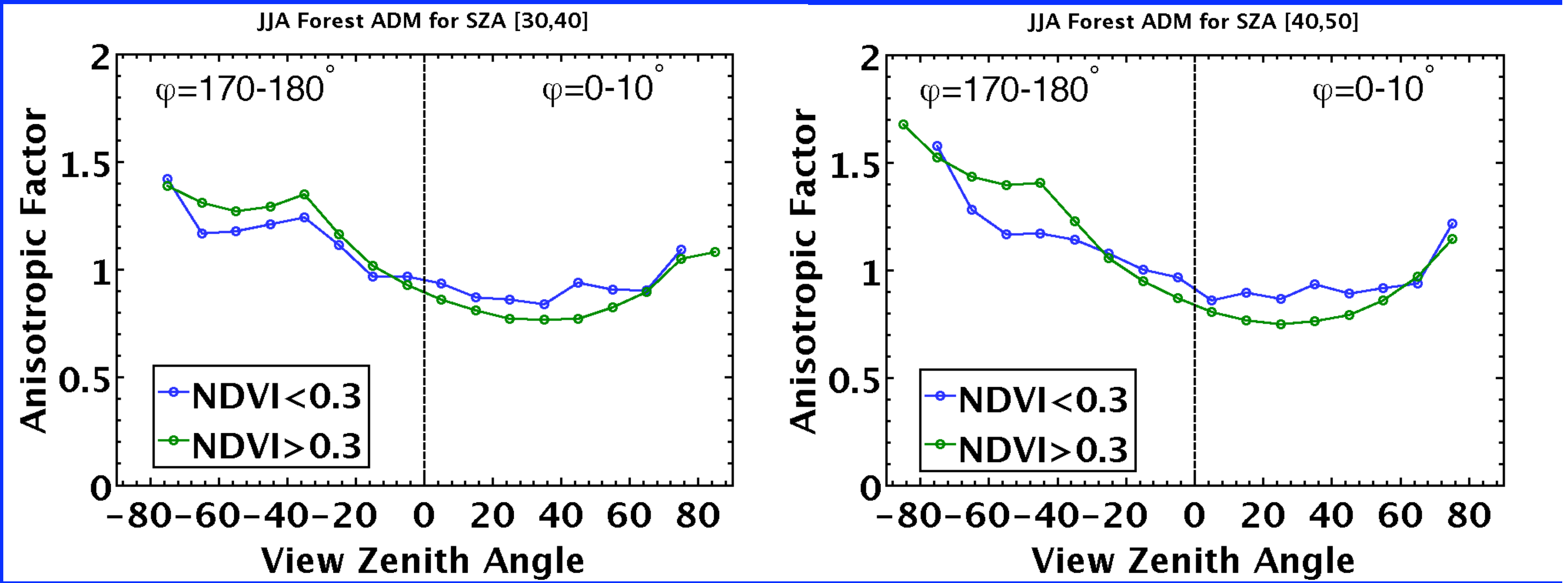


The new BRDF model reduces the RMS error for all azimuth angle ranges

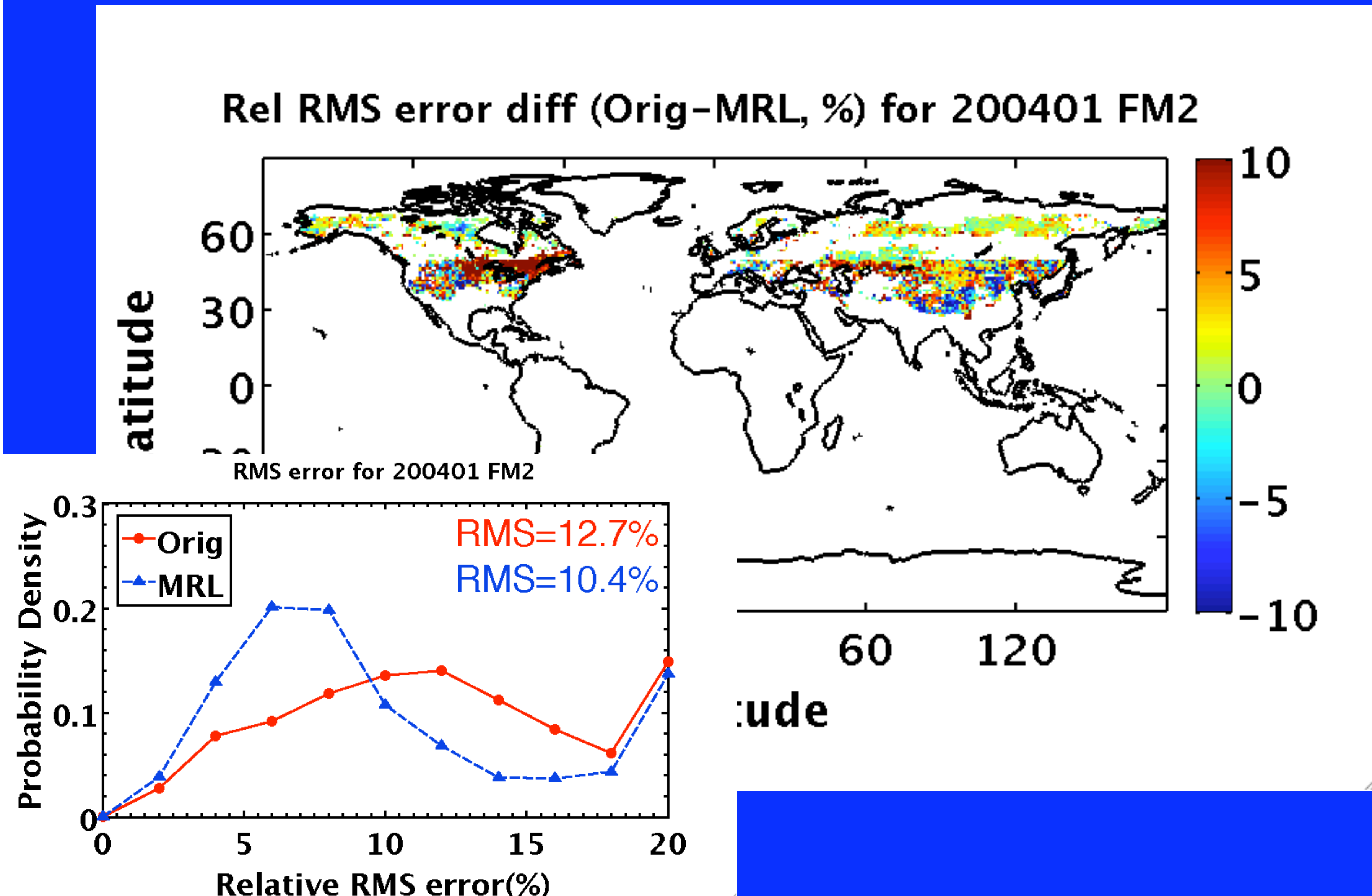


Shortwave anisotropic factor is sensitive to NDVI

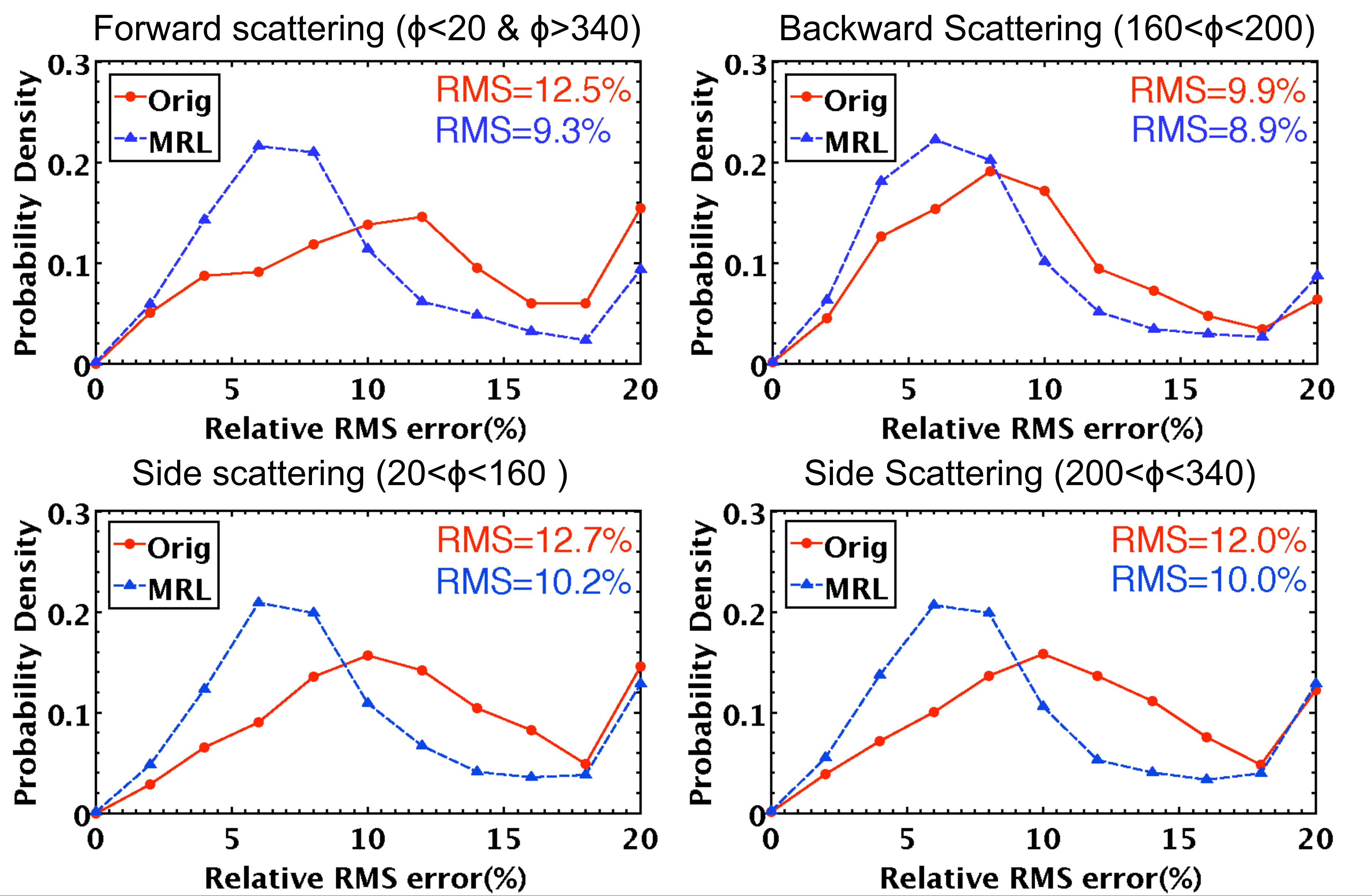
- For larger NDVI, the ADM is more anisotropic.



RossLi Model Reduces the RMS over fresh snow



The new fresh snow ADM reduces the RMS error for all azimuth angle ranges



Fresh snow anisotropic factor is sensitive to NDVI