Outline

- Ed4 Angular Distribution Models
- Cloud property differences between Ed2 and Ed4
- Flux differences due to changes in cloud properties and ADMs
- Separate Terra/Aqua ADM or combined Terra+Aqua ADM
- Validation: shortwave direct integration

Normalize predicted and observed radiance

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

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

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

1°

Observed radiance:

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

Predicted radiance:

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

1°

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

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

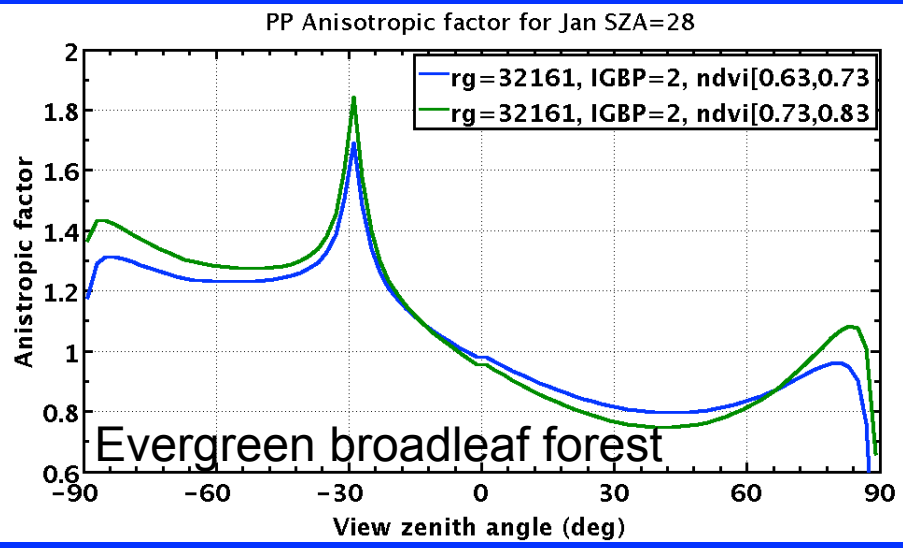
- RMS error between normalized predicted radiance and normalized observed radiance is used to assess the ADM error

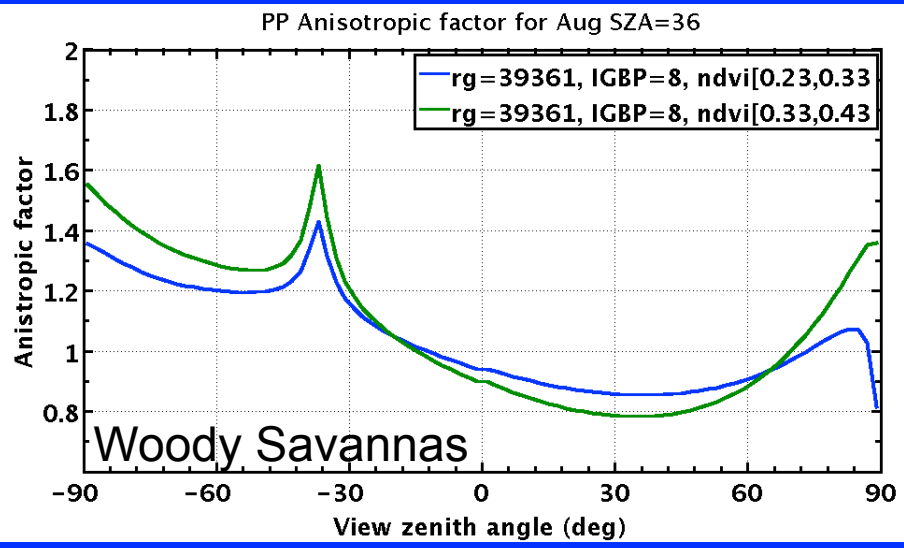
SW angular distribution model over clear land: Modified RossLi

- Collect clear-sky reflectance over 1°×1° regions for every calendar month;
- Stratify reflectance within each 1°×1° region by NDVI (0.1) and $\cos\theta_0$ (0.2);
- Apply modified RossLi fit to produce BRDF and ADM for each NDVI and $\cos\theta_0$ intervals within each 1°×1° region.

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

from Maignan et al., 2004

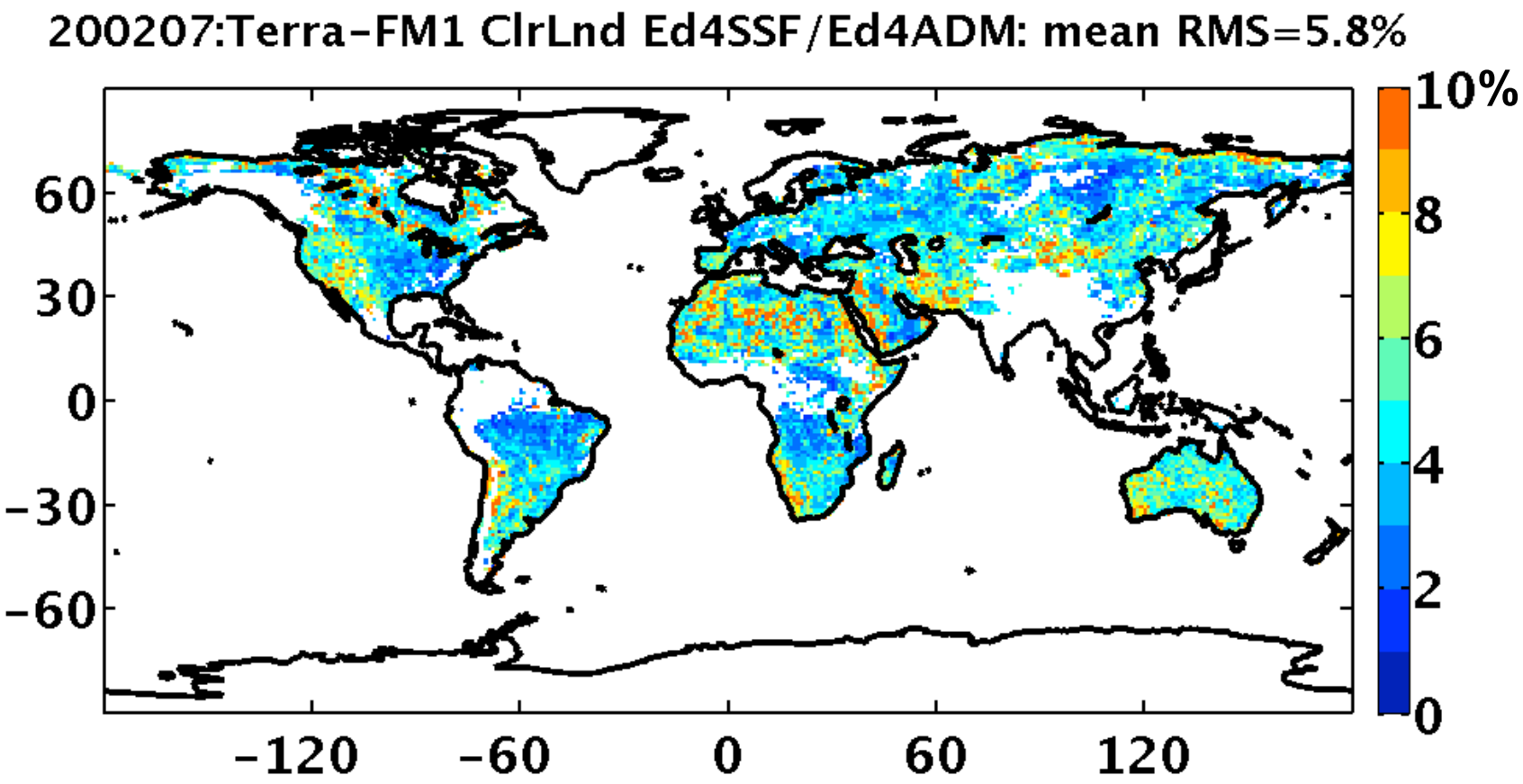




Ed4 clear land ADM reduces the RMS error

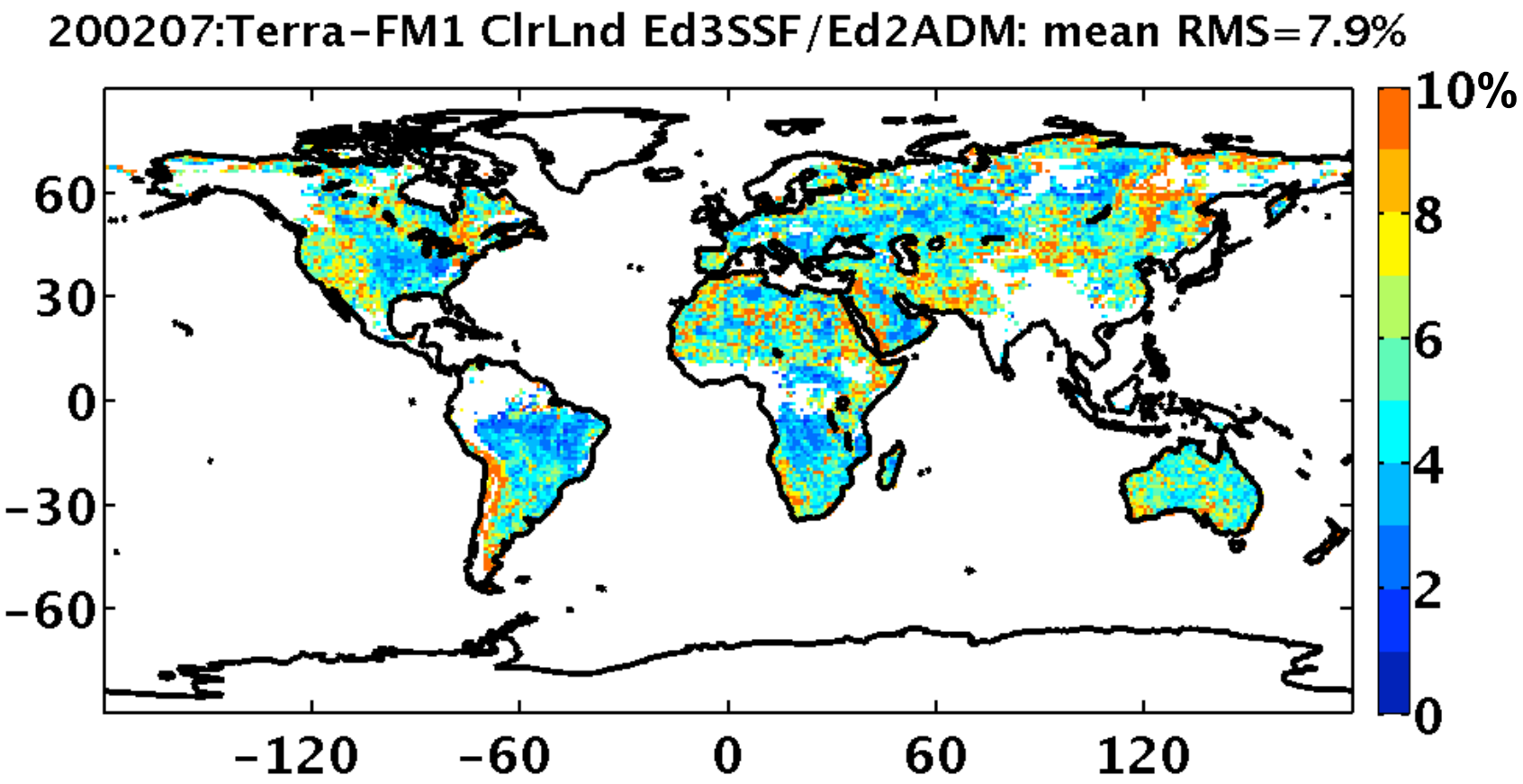
- Apply Ed4 ADM to Ed4 SSF

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

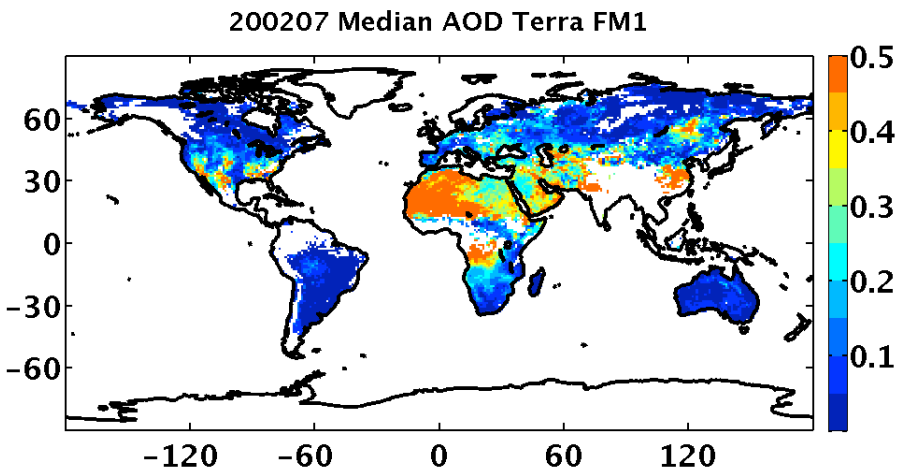


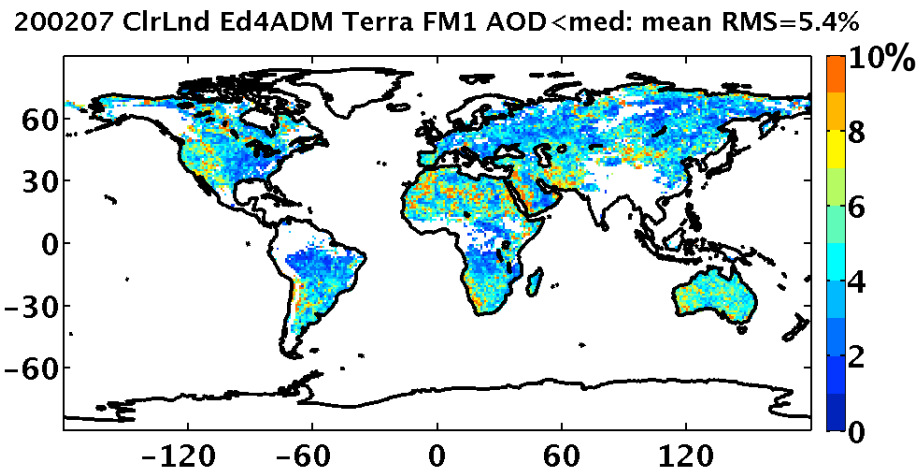
Ed4 clear land ADM reduces the RMS error

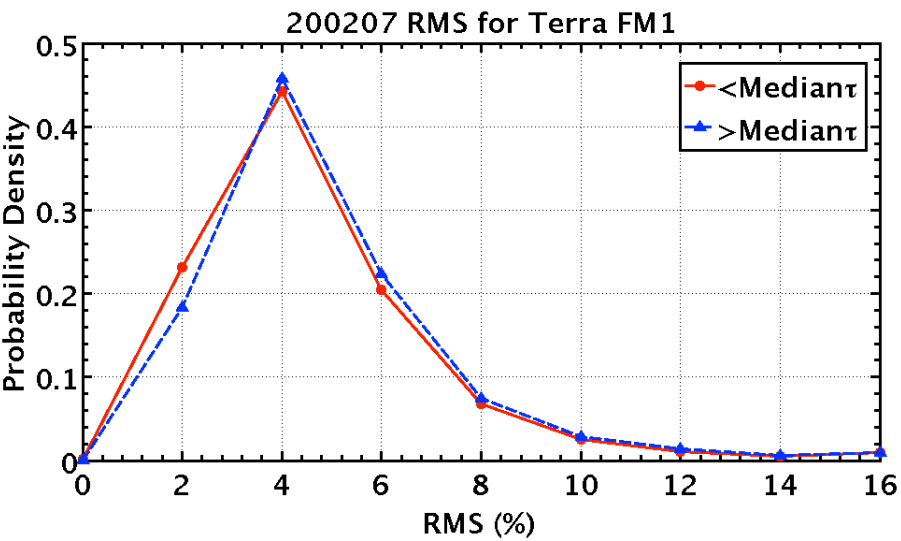
- Apply Ed2 ADM to Ed3 SSF

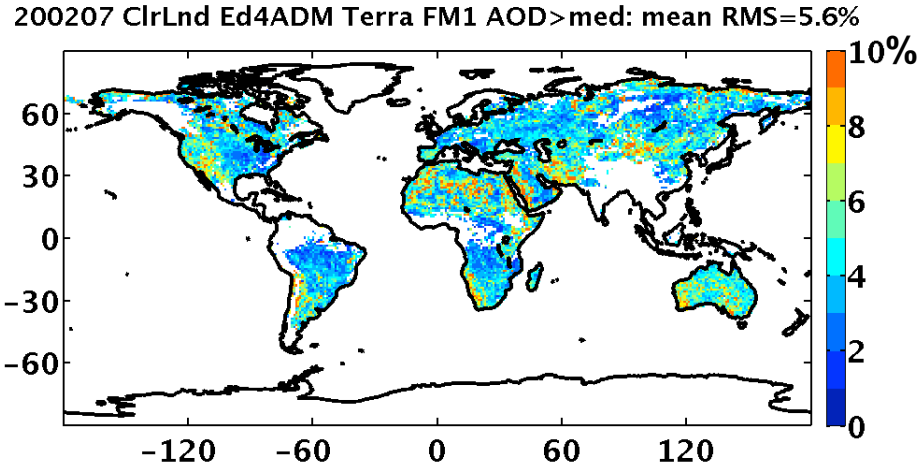


RMS error as a function of AOD





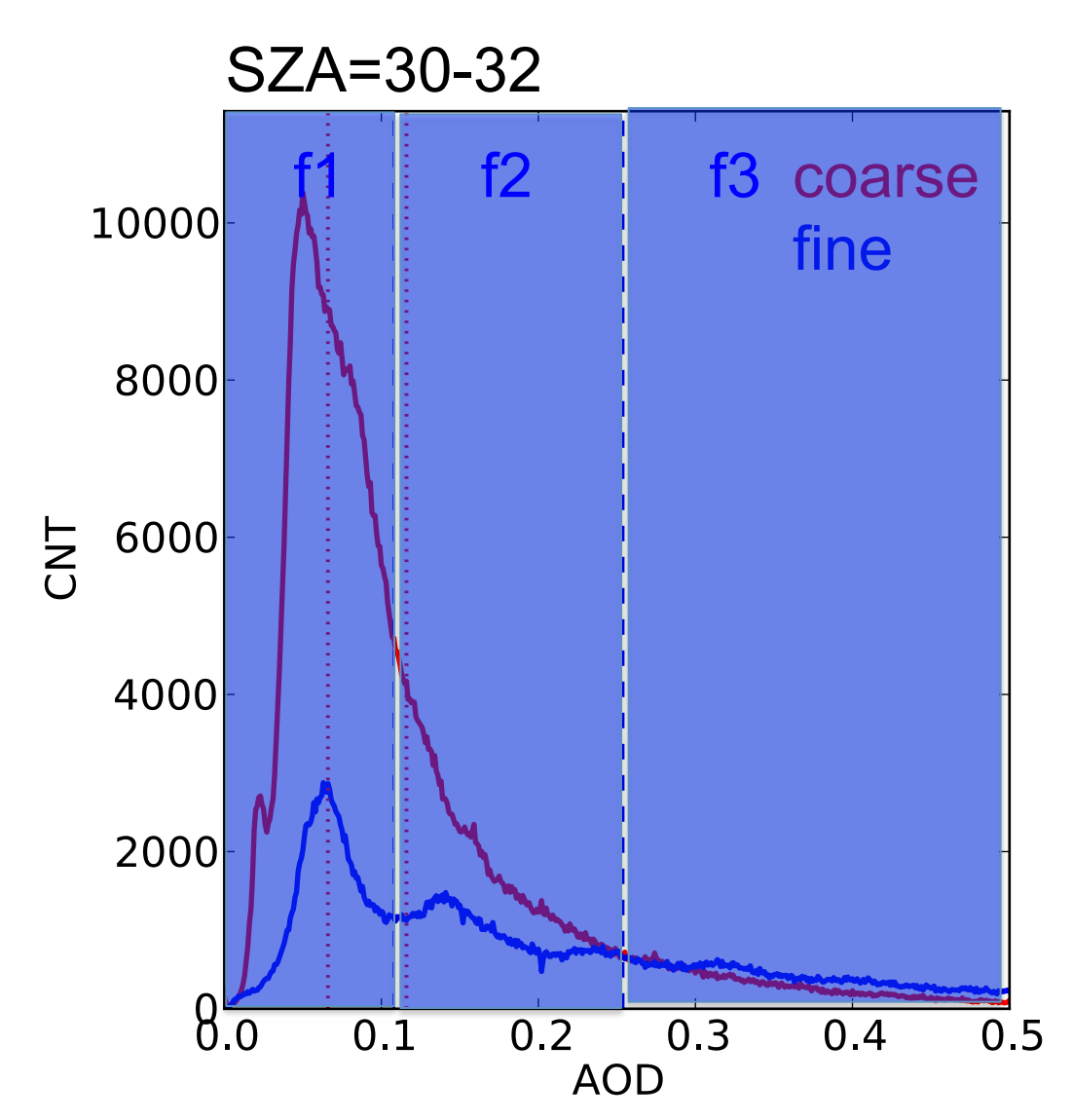




Ed4ADM over clear ocean accounts for aerosol loading and type

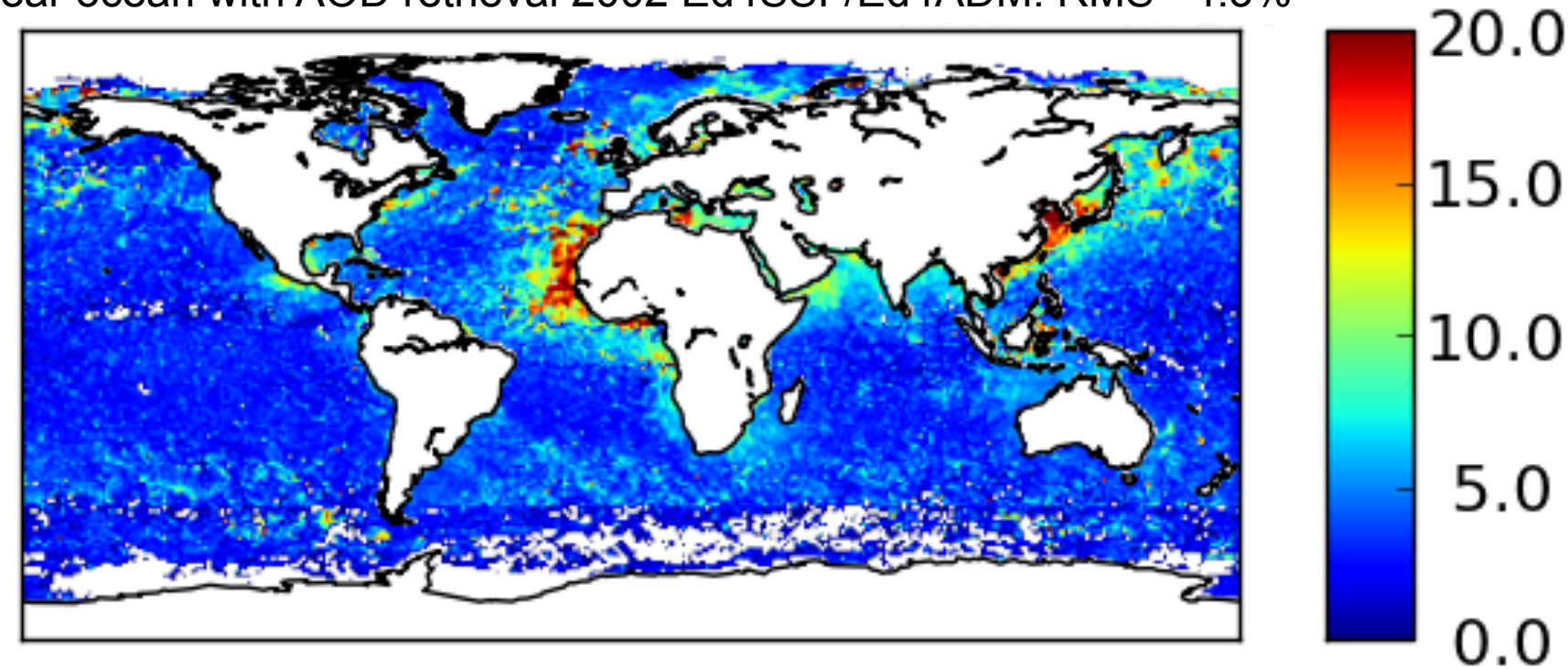
- AOD retrieval based upon a fine-mode aerosol look-up table (urban) and a coarse-mode aerosol look up table (maritime);
- Stratify fine-mode aerosols into 3 AOD bins and coarse-mode aerosols into 3 AOD bins;
- Build ADM for each AOD bin and type separately (6 ADMs).

$$\epsilon_c = \sum_{j=1}^{6}$$



Ed4ADM reduces the RMS error over clear ocean

Clear ocean with AOD retrieval 2002 Ed4SSF/Ed4ADM: RMS =4.3%

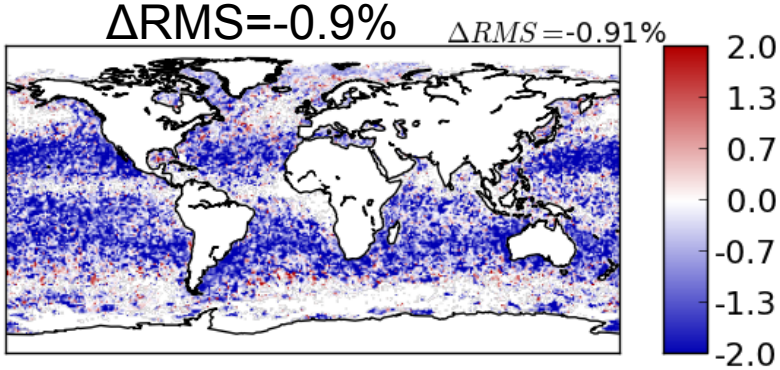


RMS error increases for the largest coarse mode AOD bin

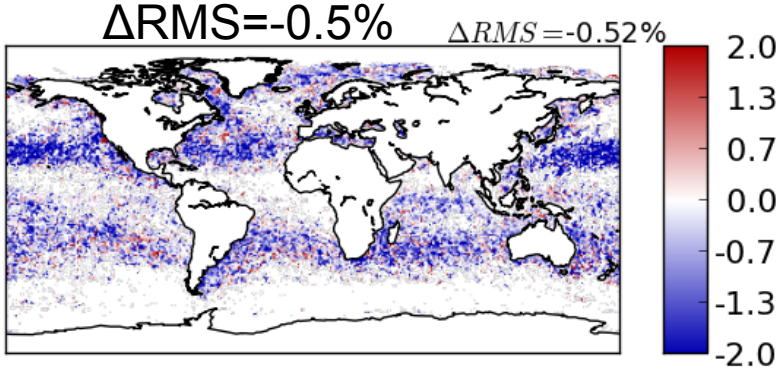
coarse-mode-like | fine-mode-like

0-33%

ΔRMS=-0.9%

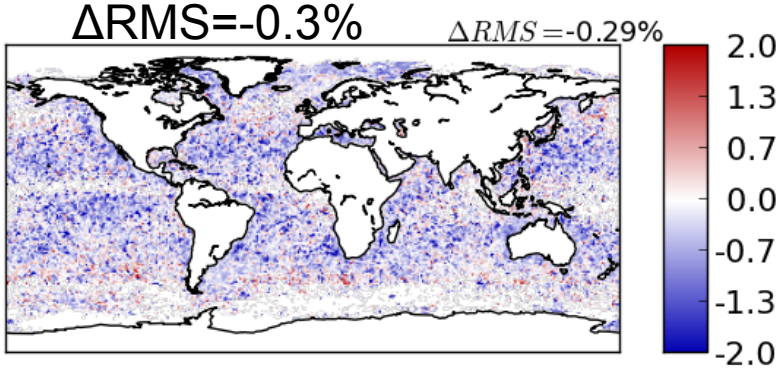


ΔRMS=-0.5%

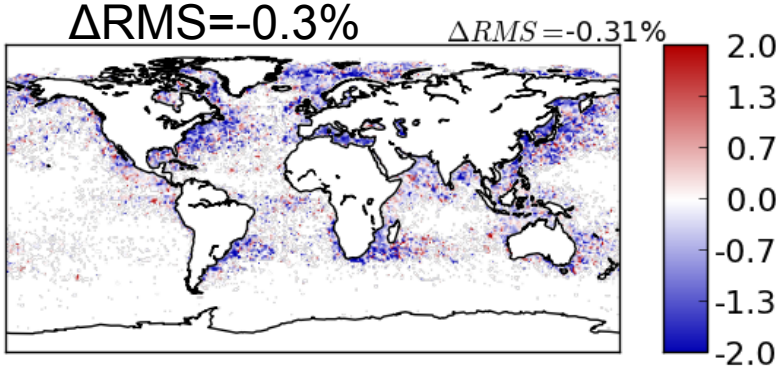


33-66%

ΔRMS=-0.3%

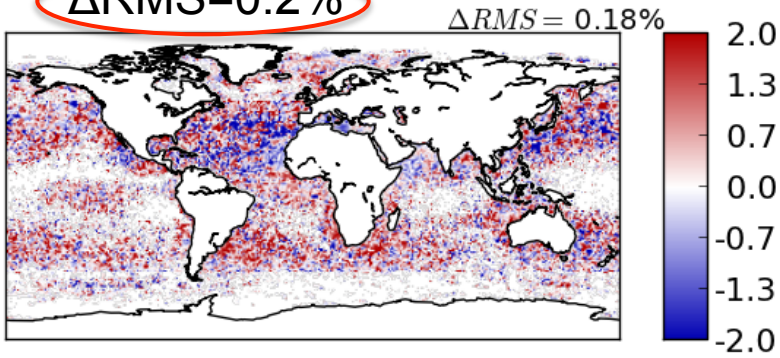


ΔRMS=-0.3%

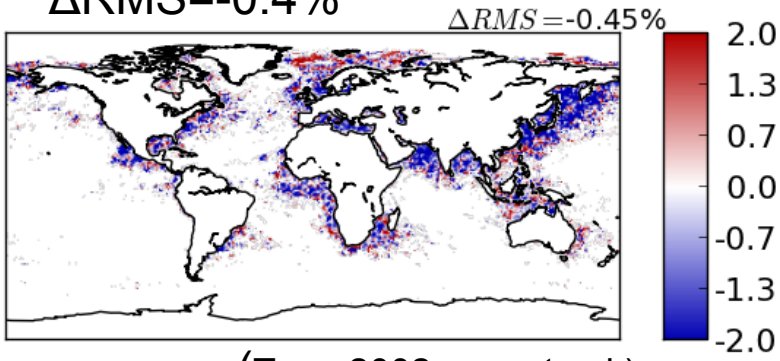


66-100%

ΔRMS=0.2%



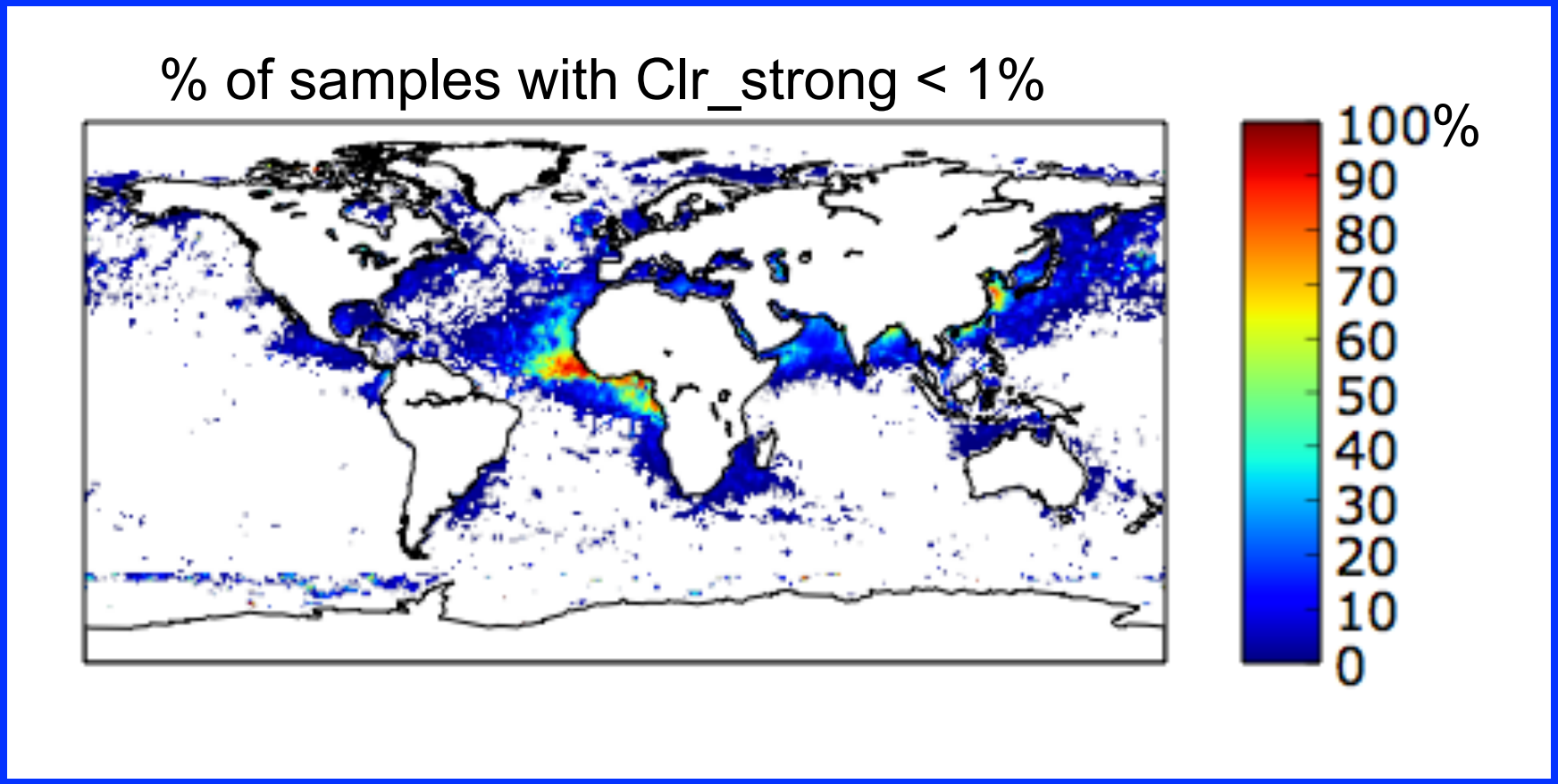
ΔRMS=-0.4%



(Terra 2002 cross-track)

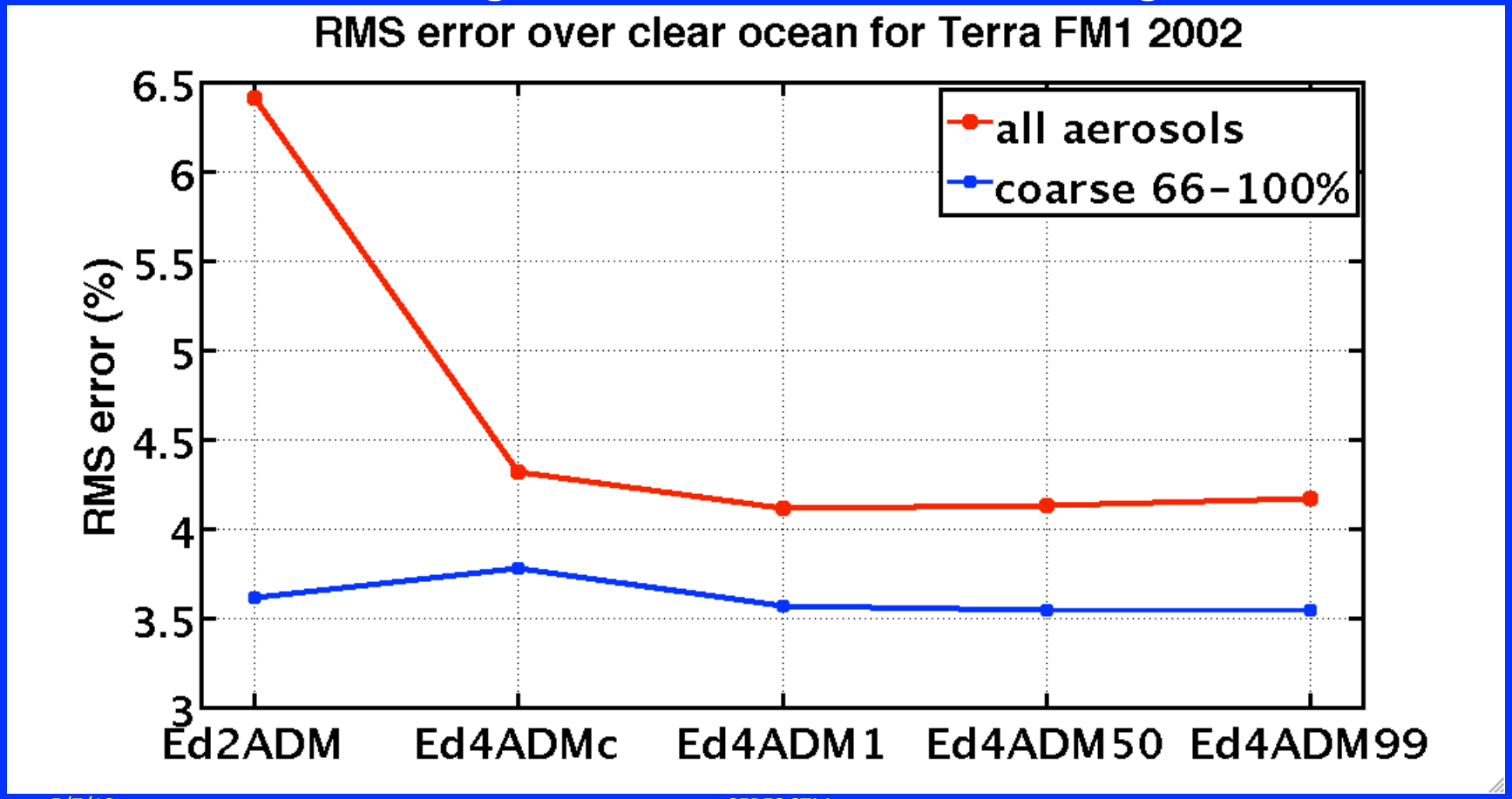
Is the largest coarse mode AOD bin contaminated by clouds?

- Use cloud mask clear_Strong percentage to eliminate footprints that are possibly contaminated by clouds



Develop clear-ocean ADM excluding questionable clear FOVs

- Ed4ADMc: including all clear FOVs;
- Ed4ADM1: excluding clear FOVs with clear_strong < 1%;
- Ed4ADM50: excluding clear FOVs with clear_strong < 50%;
- Ed4ADM99: excluding clear FOVs with clear_strong < 99%;



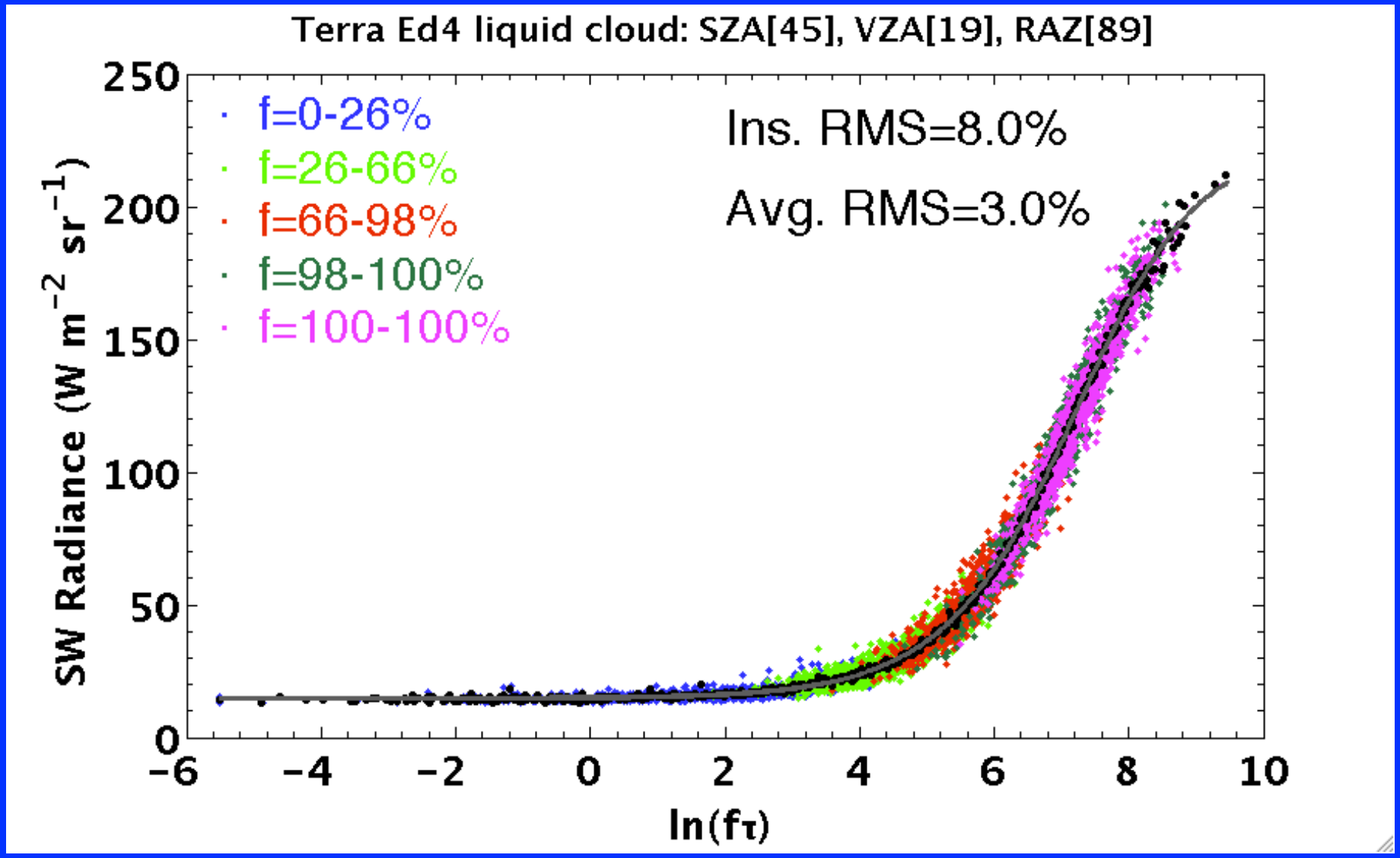
Angular distribution model over cloudy ocean

- For glint angle > 20°, or glint angle < 20° and $\ln(f\tau)$> 6:
  - Average instantaneous radiances into 775 intervals of $\ln(f\tau)$ for each angular bin (2°) separately for liquid, mixed, and ice clouds;
  - Apply a five-parameter sigmoidal fit to mean radiance and $\ln(f\tau)$;

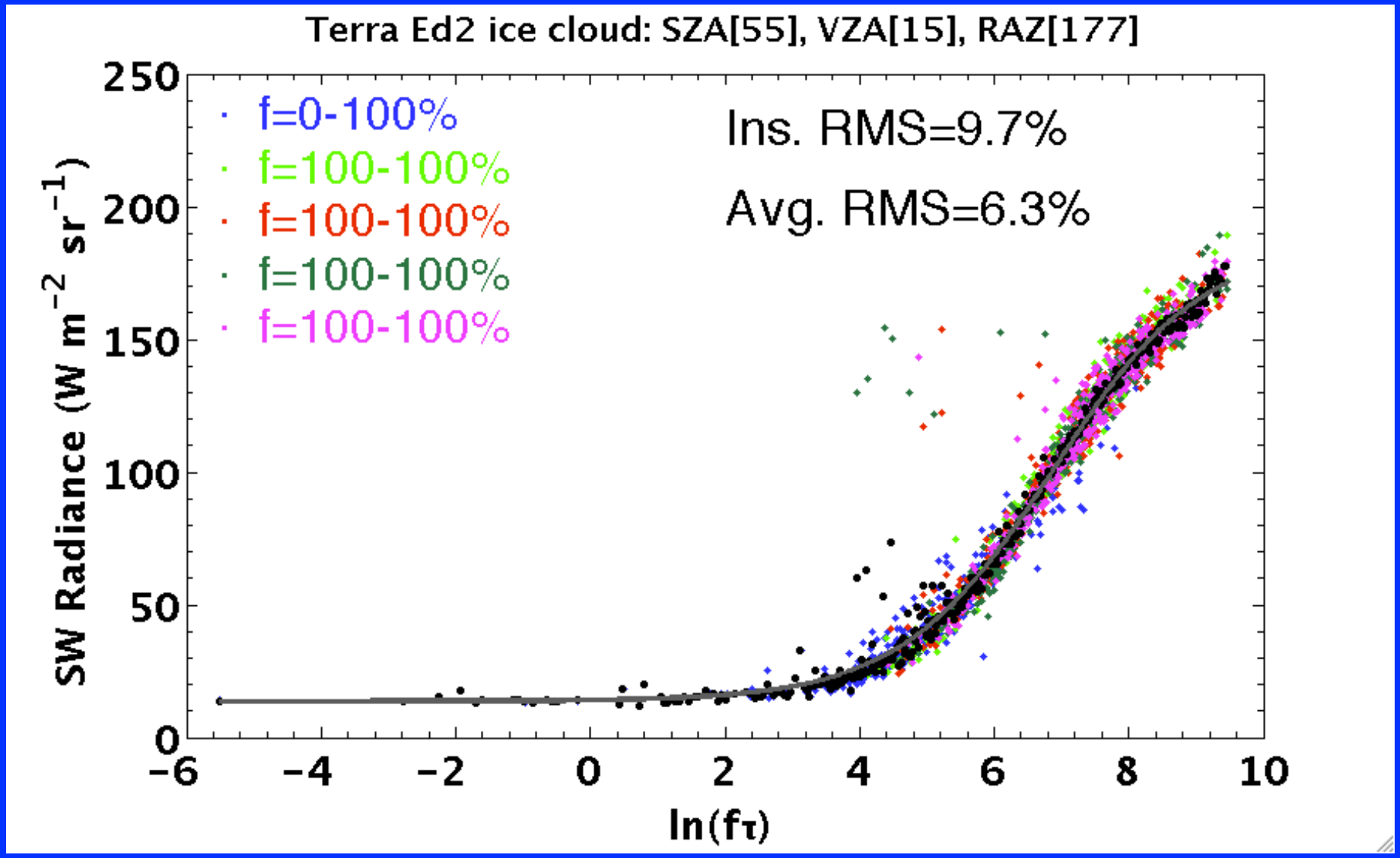
$$I = I_0 + \frac{a}{[1 + e^{-(x-x_0)/b}]^c}$$

- For glint angle < 20° and $\ln(f\tau)$ < 6:
  - Calculate mean radiance for 6 wind speed bins and 4 $\ln(f\tau)$ bins;
  - Use mean radiance to build ADM

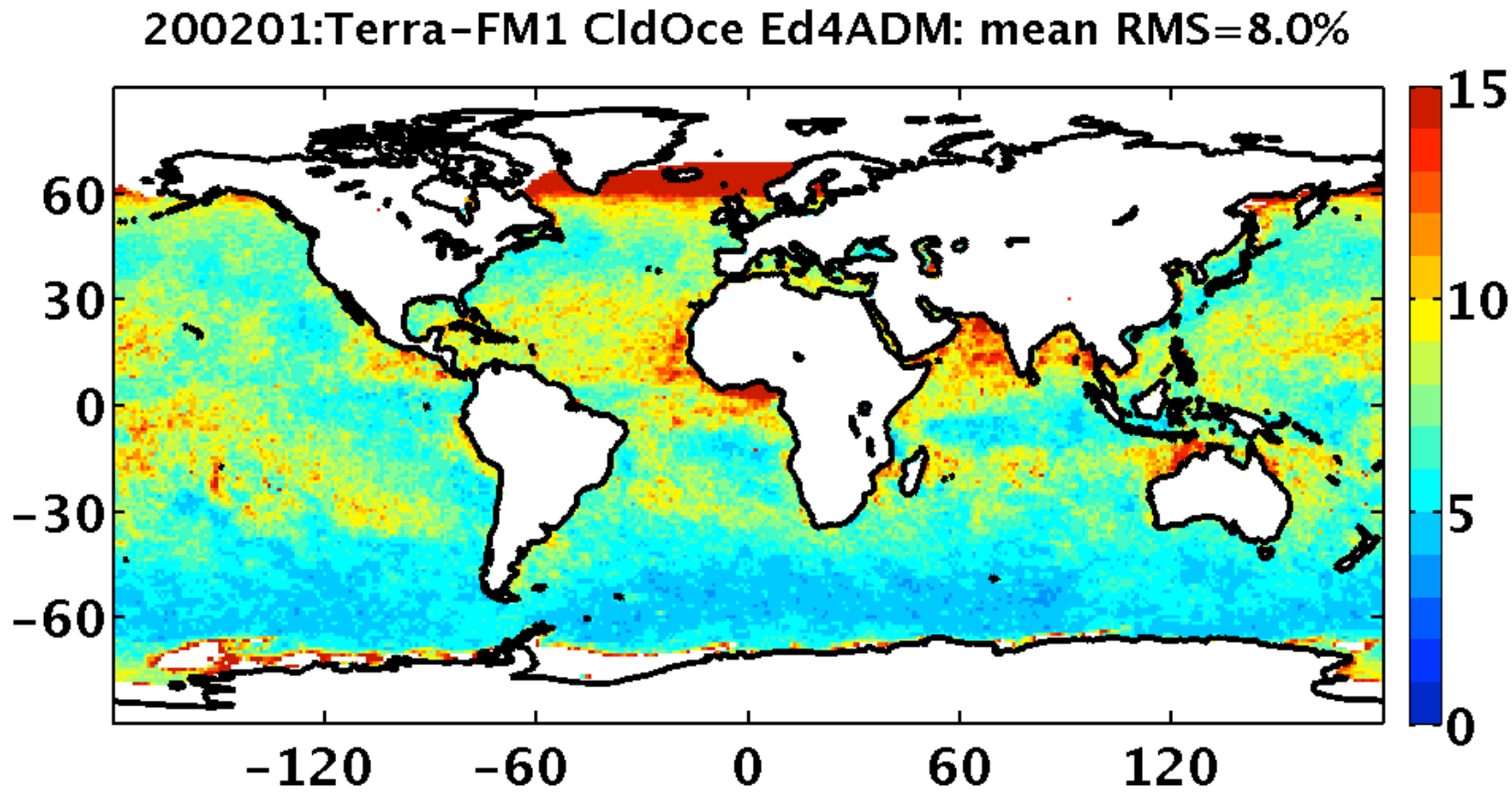
Ed4SSF produces tighter sigmoidal fit over ocean: liquid



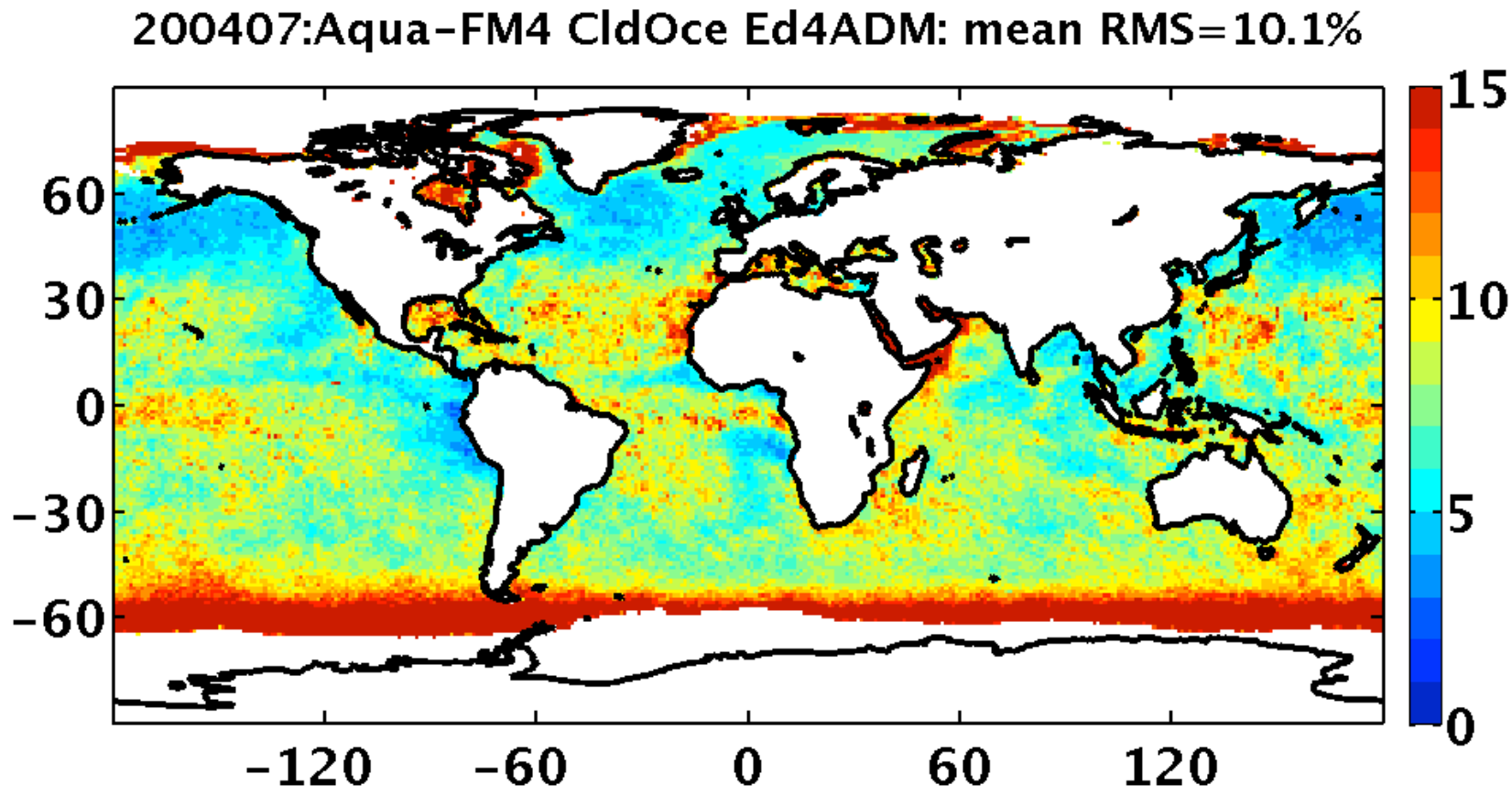
Ed4SSF produces tighter sigmoidal fit over ocean: ice



Ed4 ADM decreases the RMS error over cloudy ocean: Terra FM1



Ed4 ADM decreases the RMS error over cloudy ocean: Auua FM4



Angular distribution model over cloudy land/desert

- Derive cloudy area contribution from observed radiance:

$$fI^{cld}(\mu_0,\mu,\phi) = I(\mu_0,\mu,\phi) - (1-f)\frac{\mu_0 E_0}{\pi}\rho^{clr}(\mu_0,\mu,\phi) - f\frac{\mu_0 E_0}{\pi}\left[\rho^{clr}(\mu_0,\mu,\phi)e^{\frac{-\tau}{\mu_0}}e^{\frac{-\tau}{\mu}} + \overline{\alpha}^{clr}\frac{t^{cld}(\tau,\mu_0)t^{cld}(\tau,\mu)}{1-\overline{\alpha}^{clr}\overline{\alpha}^{cld}(\tau)}\right]$$

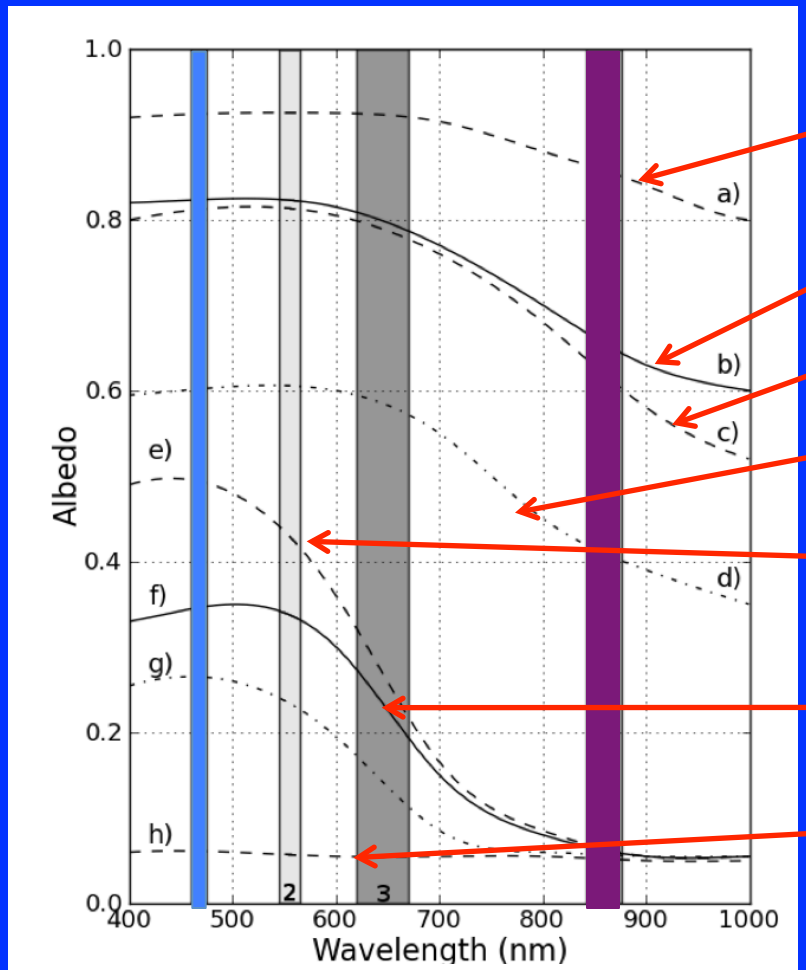
- Average instantaneous fI^{cld} into 380 intervals of $\ln(f\tau)$ for each angular bin (5°) for three cloud phases;
- Apply a five-parameter sigmoidal fit to mean fI^{cld} and $\ln(f\tau)$;

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

- Ed4 ADM reduces the RMS error over cloudy land.

Sea ice index to quantify the brightness of sea ice surface

$$\eta = 1 - \frac{\rho_{0.47} - \rho_{0.86}}{\rho_{0.47} + \rho_{0.86}}$$



Rosel et al 2012, surface values

Snow

Bare ice

Wet snow

Melting first year ice

Young melting pond

Melting ponds

Open water

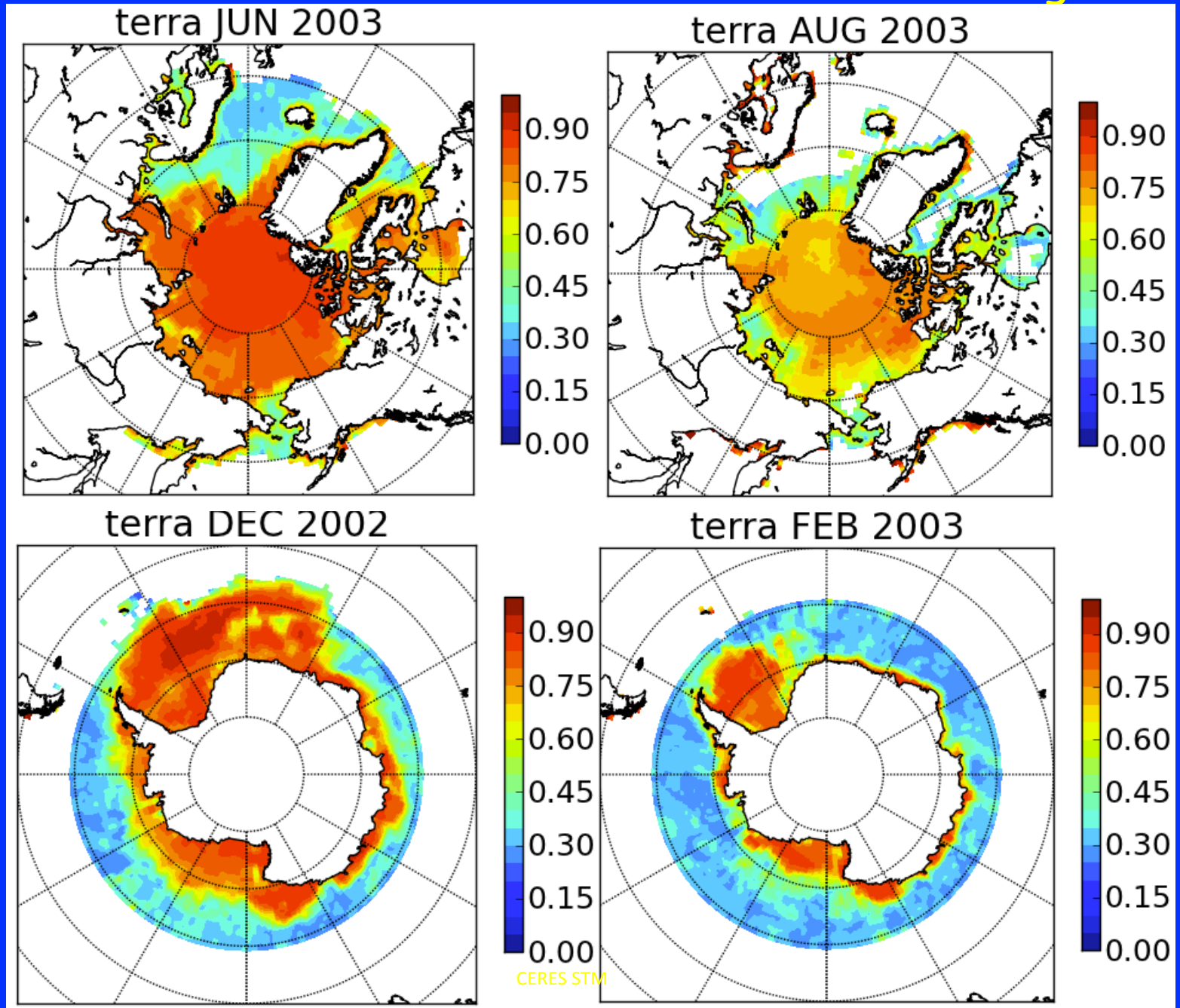
High sea ice index

~0.8-1.0

~0.1-0.5

Low sea ice index

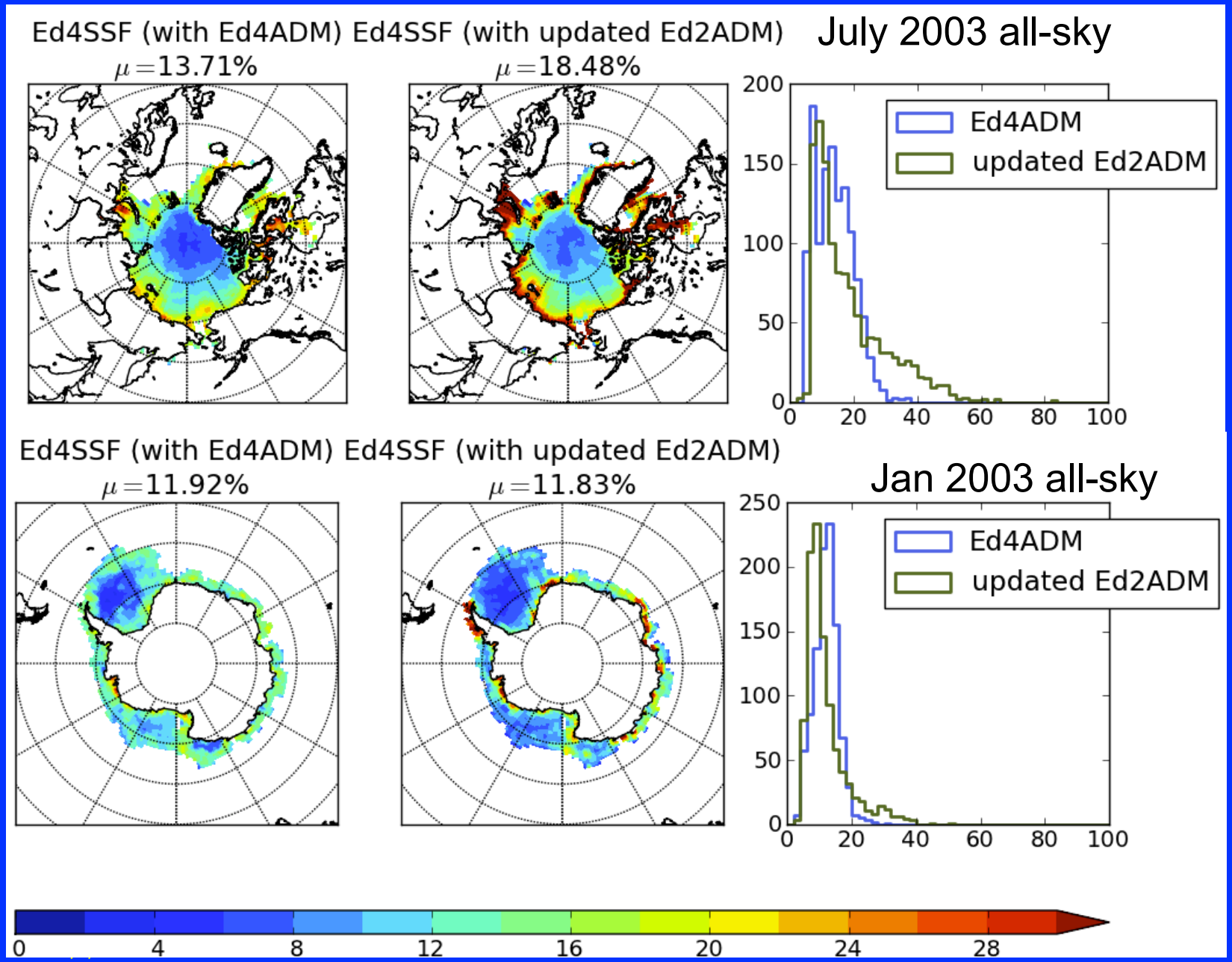
Sea ice index decreases as ice starts melting



Shortwave Ed4ADMs over sea ice

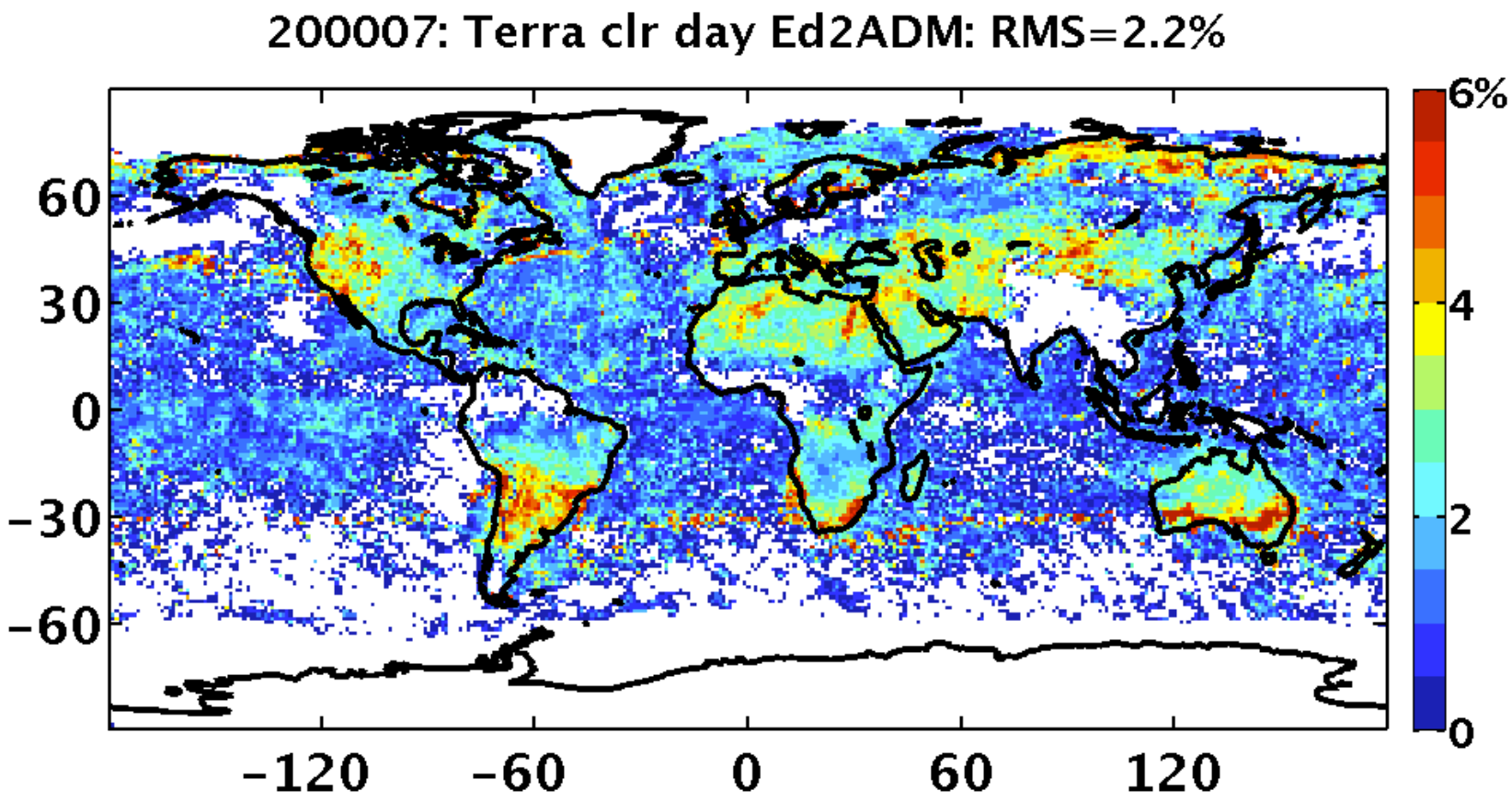
- Clear-sky
  - 6 sea ice fraction bins
  - 3 sea ice index bins for scenes with sea ice fraction >99%
- Partly cloudy
  - 4 cloud fraction bins
  - 2 ln(τ) bins
  - 6 sea ice fraction bins
  - 3 sea ice index bins for scenes with sea ice fraction >99%
- Overcast
  - Linear fit between mean reflectance and ln(τ), separately for liquid and ice clouds and 5 sea ice index ranges derived from monthly maps

RMS error for sea ice



Clear-sky longwave/window angular distribution models

- Over clear land/ocean/snow/ice:
  - Ed4 ADMs increased the surface skin temperature (Ts) bins and interpolation between the Ts bins;

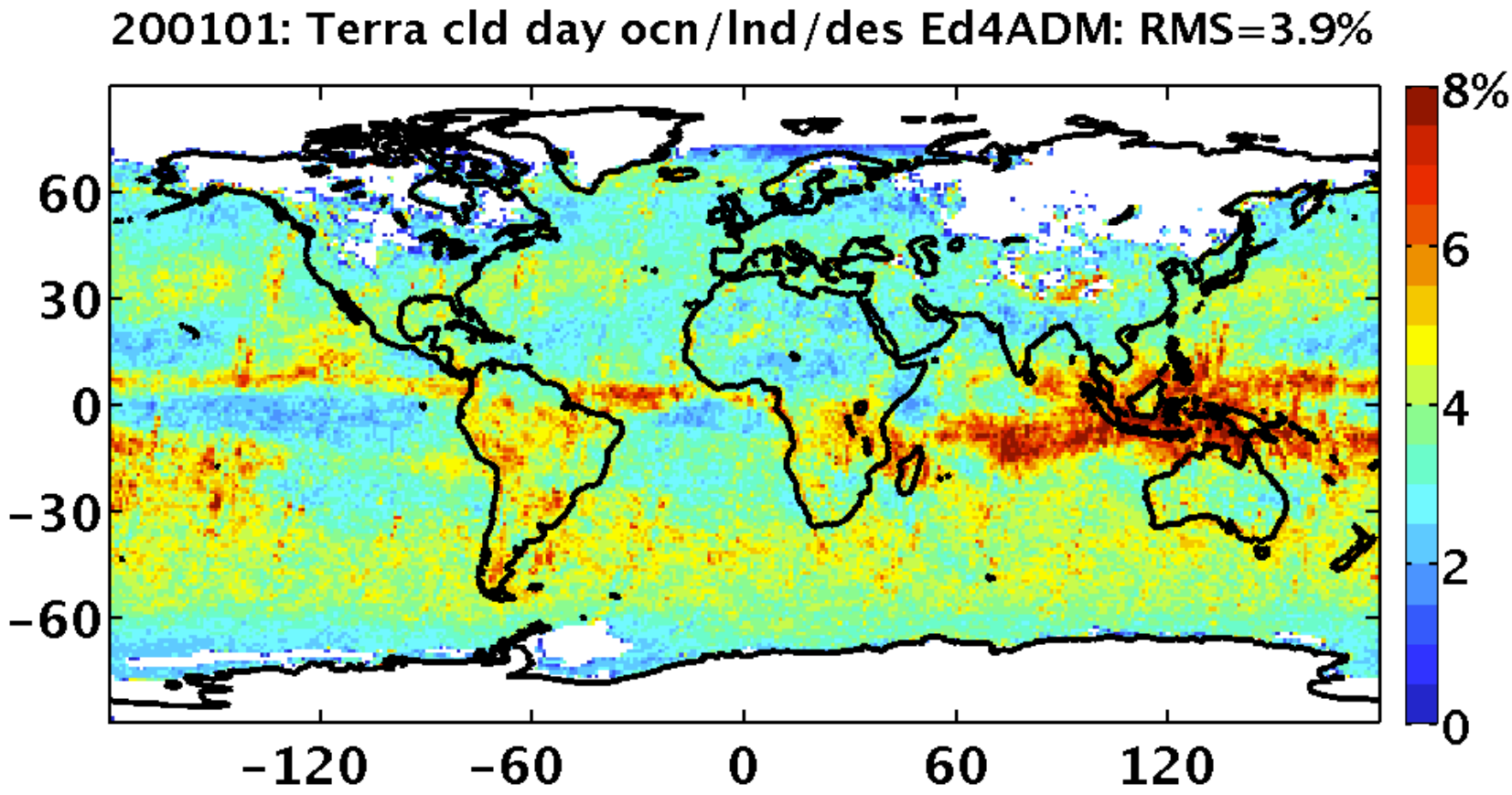


Cloudy-sky LW/WN angular distribution models

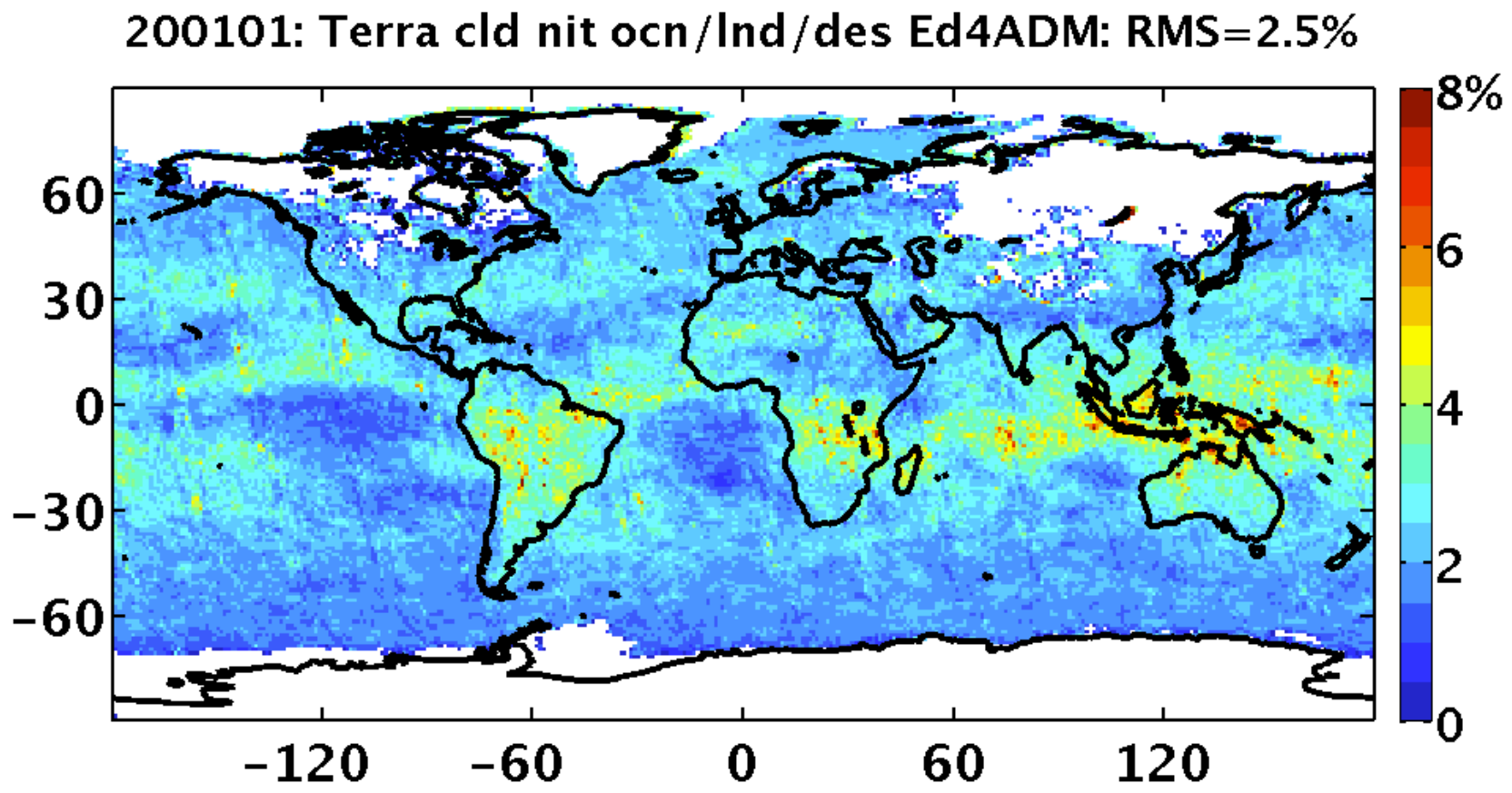
- Ed2 ADM uses third-order polynomial fits between radiance and 'pseudoradiance' (Ψ) to determine anisotropic factor;
- Ed4 ADM uses mean radiance for each 1 $Wm^{-2}sr^{-1}$ Ψ bin, and interpolates between the Ψ bins. Third-order polynomial fits are used as backup;
- Will evaluate if more bins are needed.

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

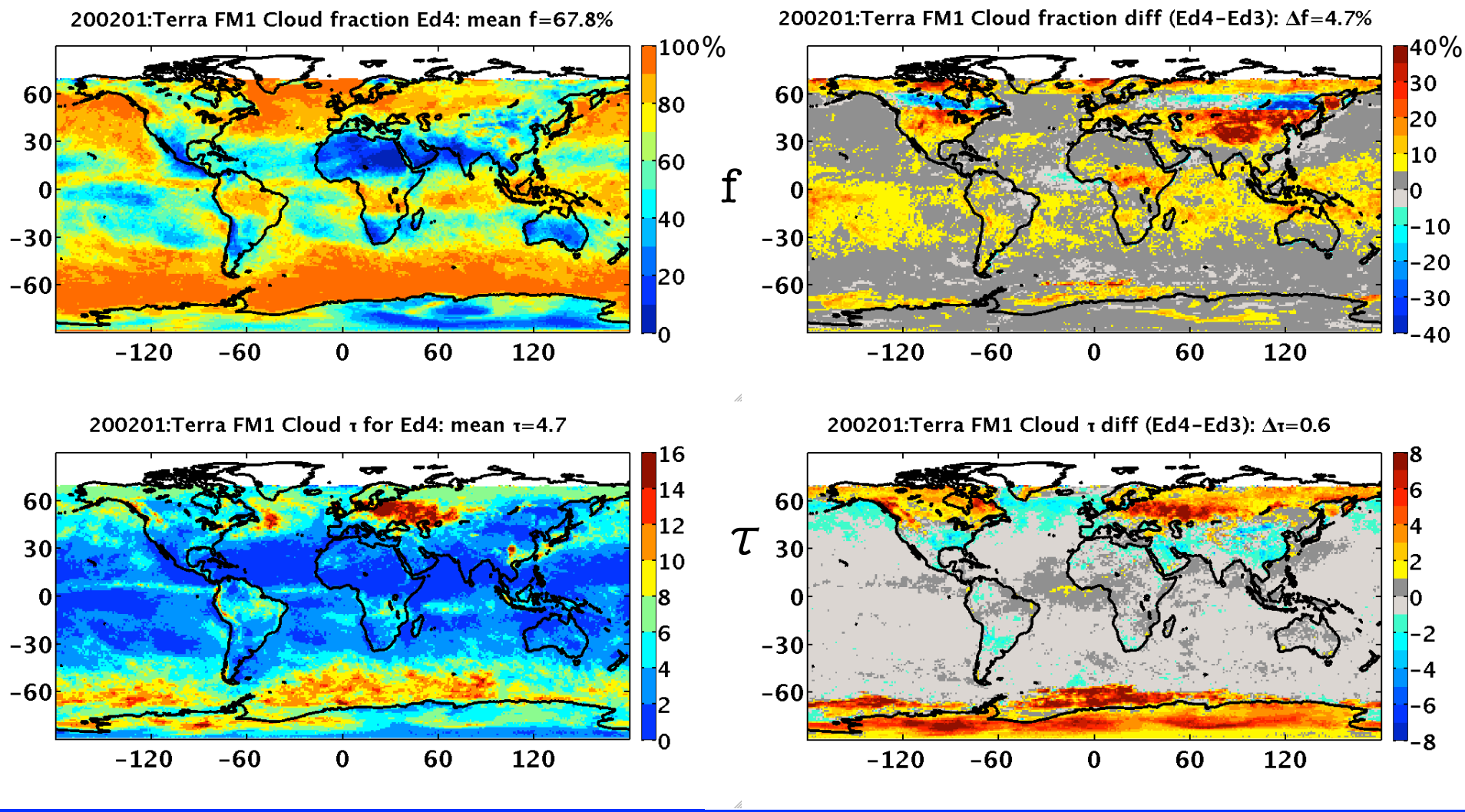
LW RMS error comparison between Ed2ADM and Ed4ADM: Jan 2001 daytime Terra



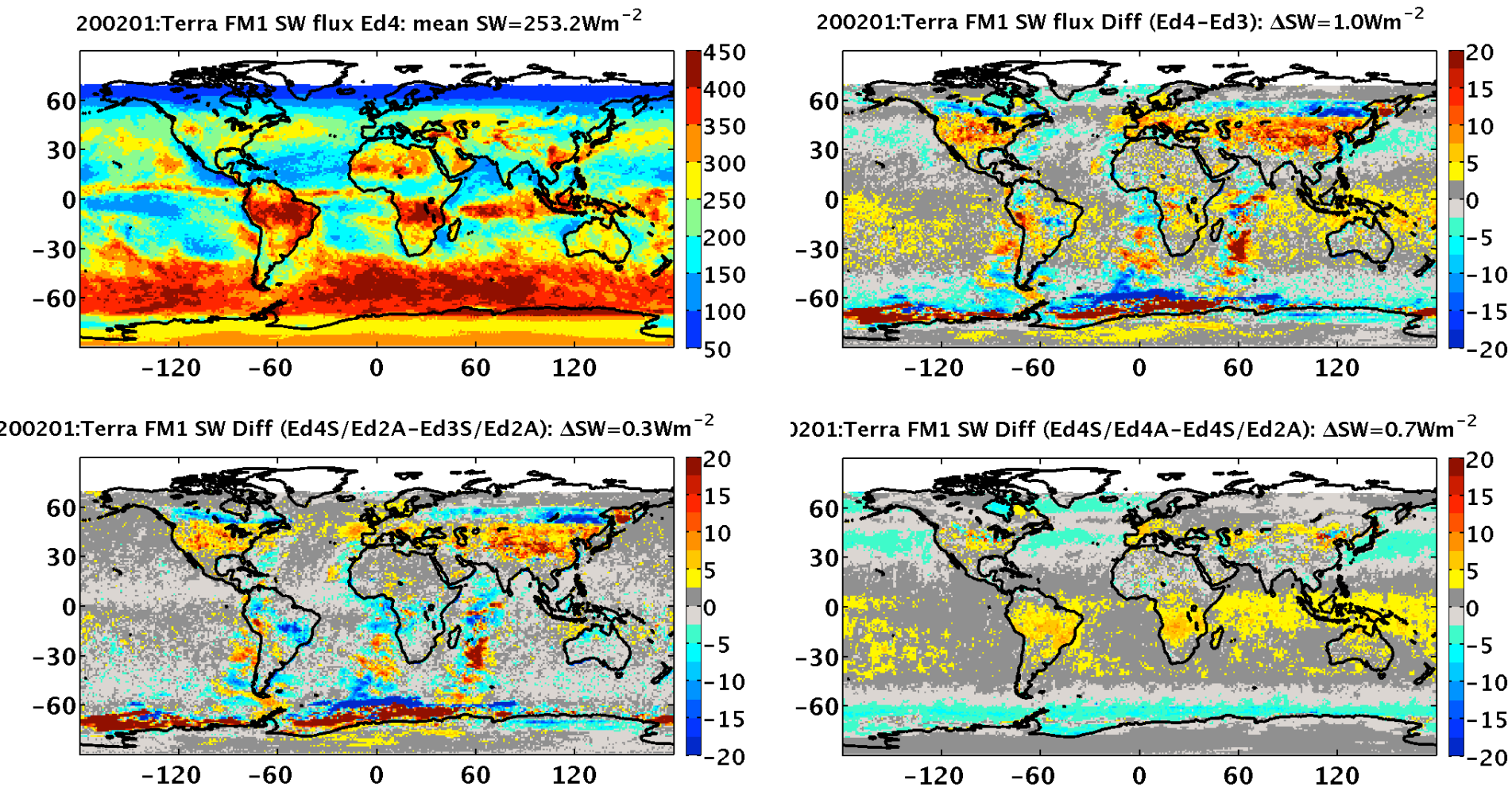
LW RMS error comparison between Ed2ADM and Ed4ADM: Jan 2001 nighttime Terra



Daytime Cloud property difference between Ed3 and Ed4

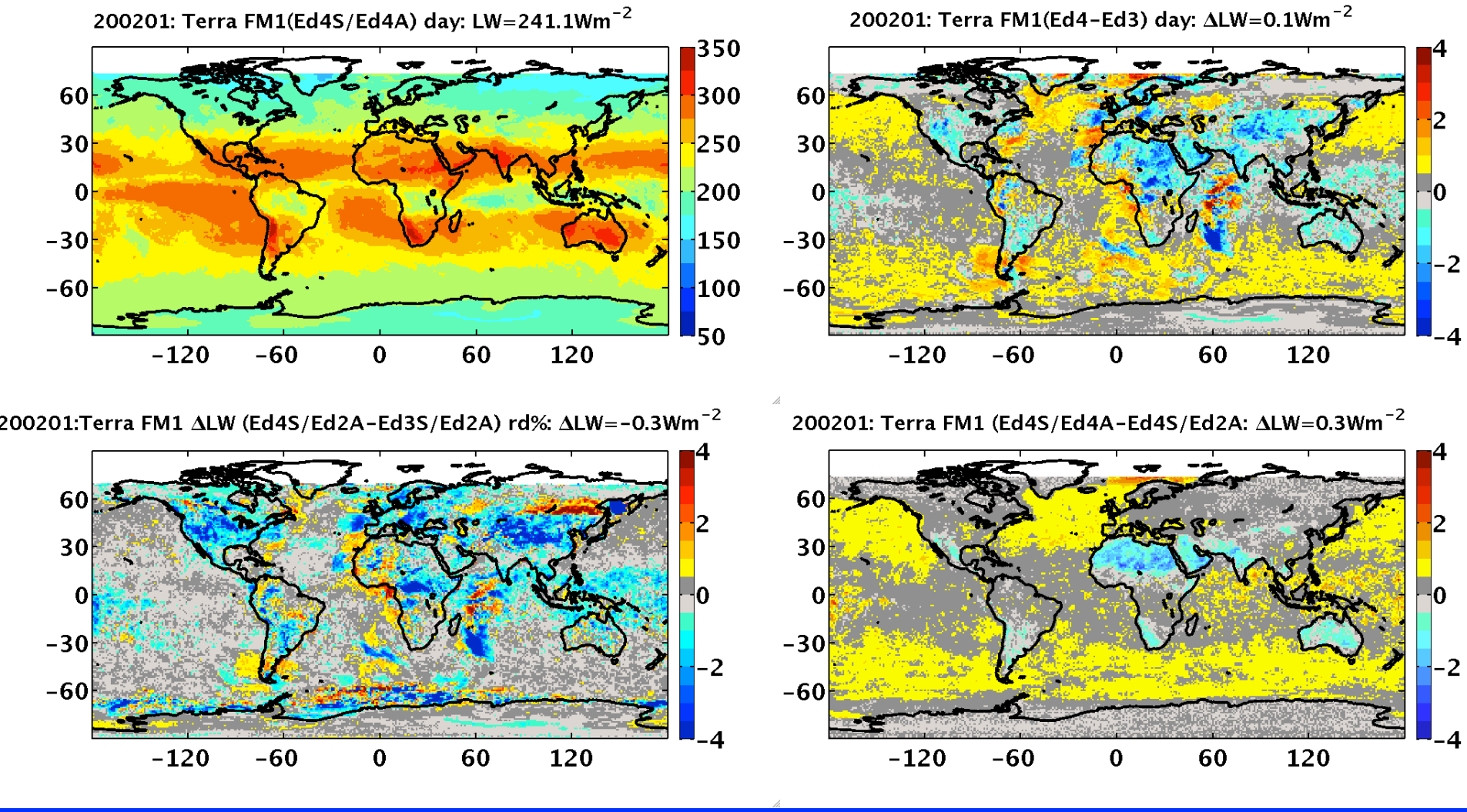


SW flux change between Ed3 and Ed4



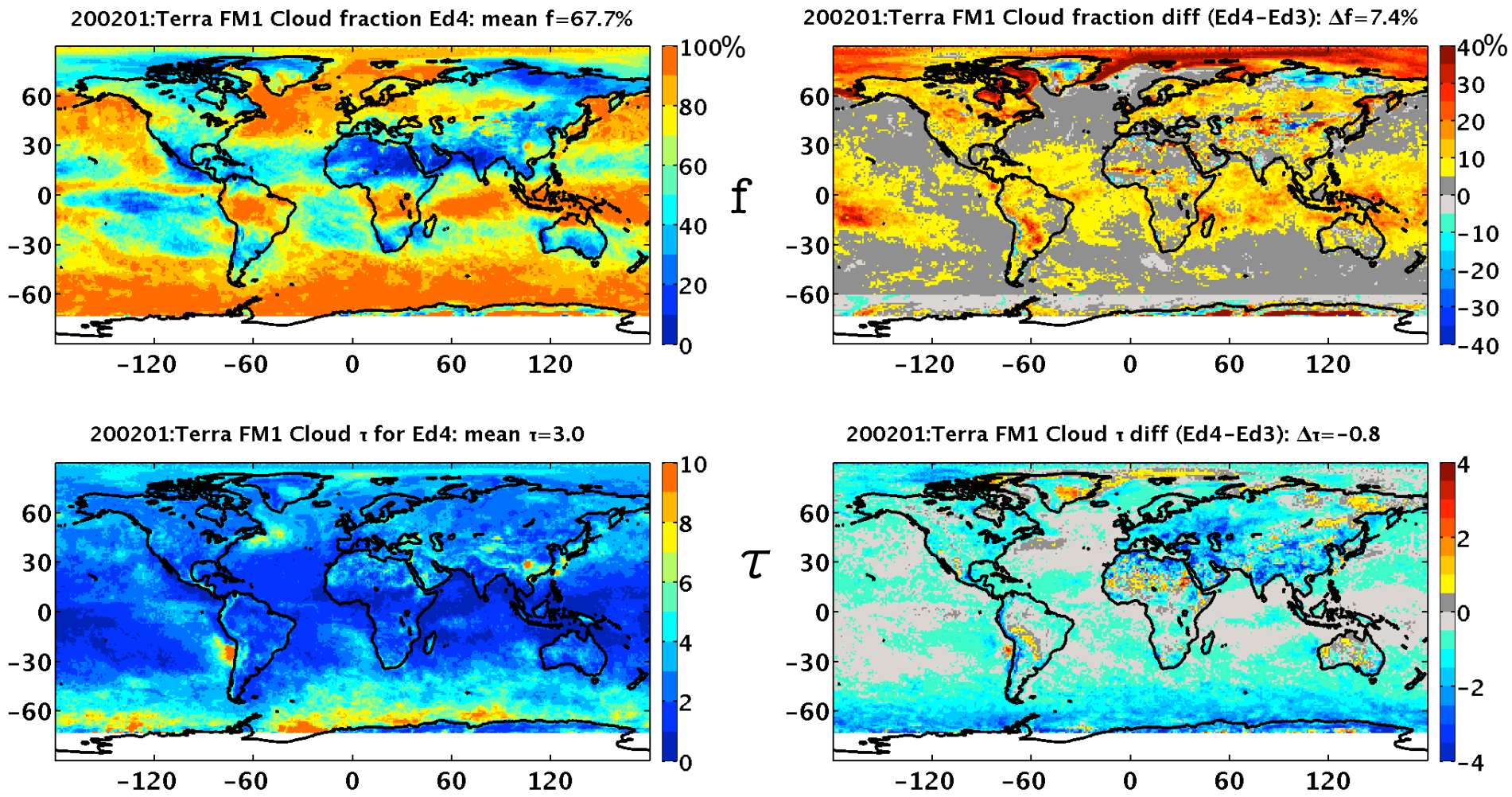
Ed4ADM: clear land, cloudy ocean, cloudy land, and sea ice

Daytime LW flux change between Ed3 and Ed4

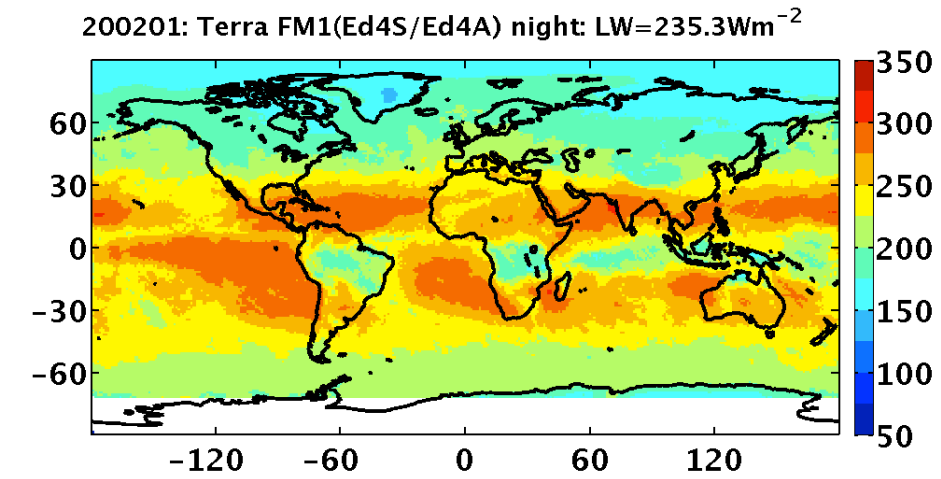


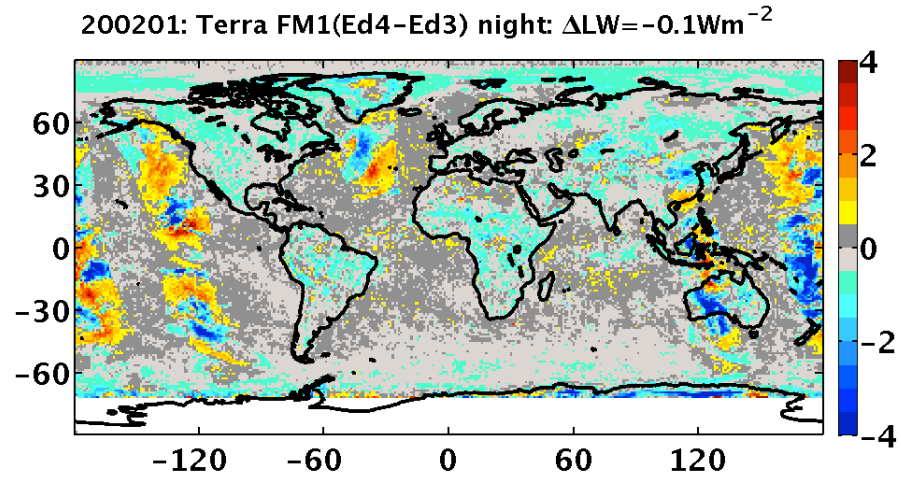
Ed4ADM: clear ocean/land/desert, cloudy ocean/land/desert

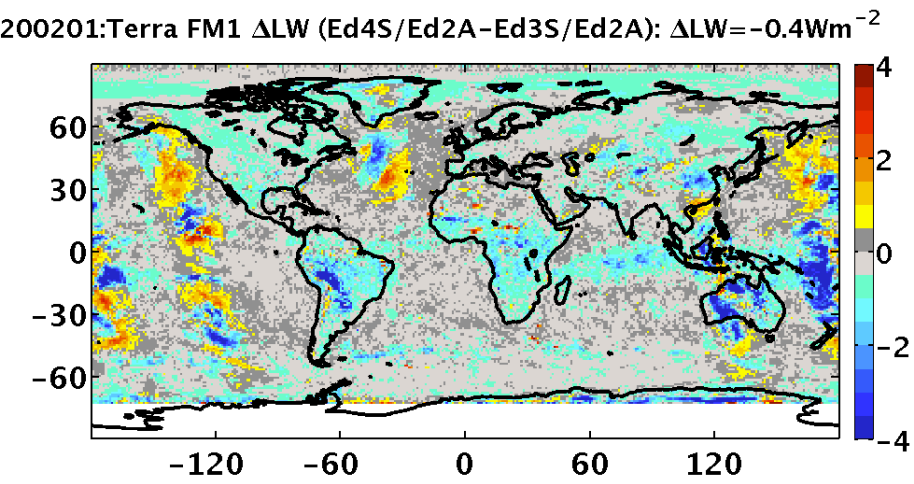
Nighttime Cloud property difference between Ed3 and Ed4

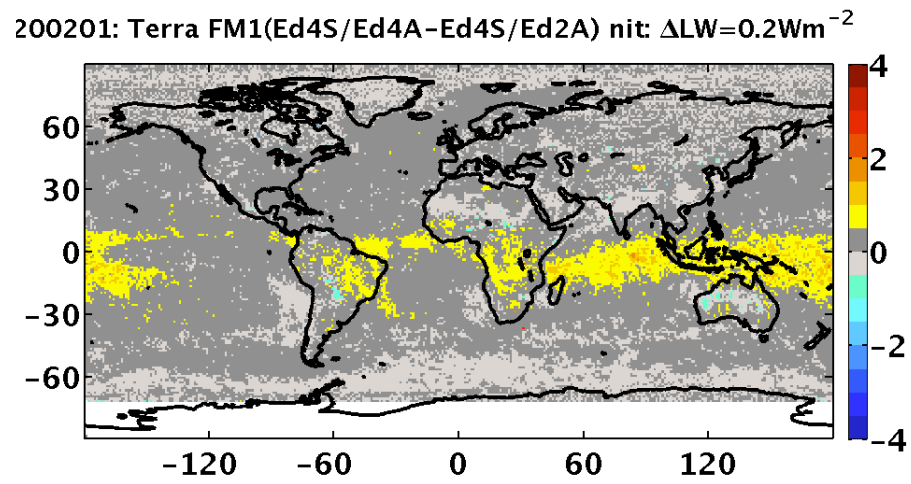


Nighttime LW flux change between Ed3 and Ed4



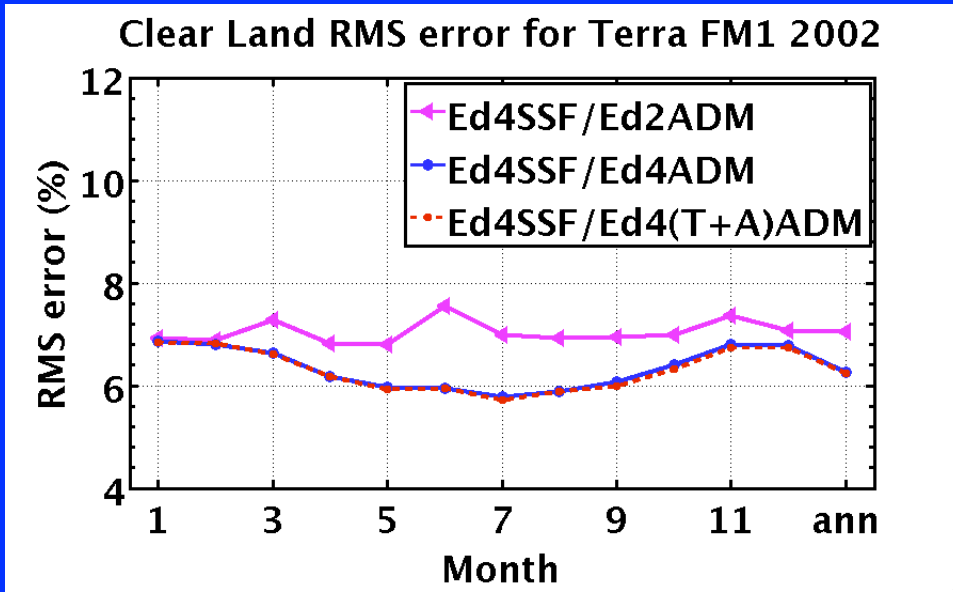


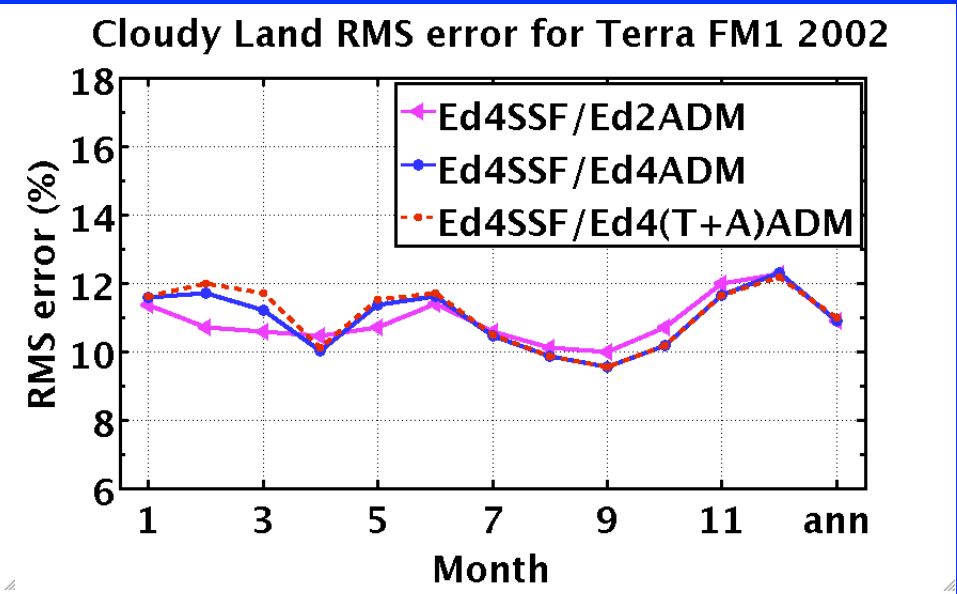


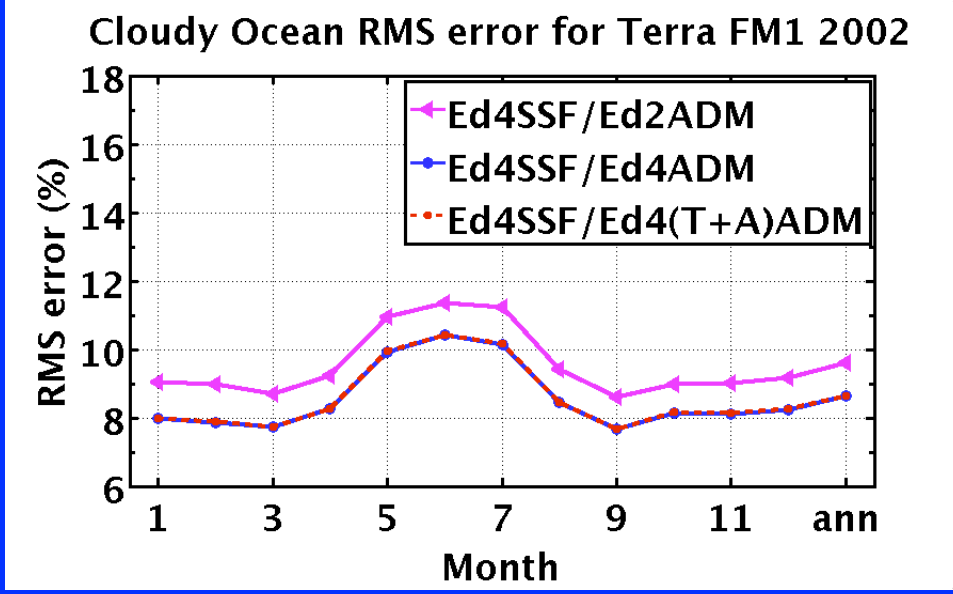


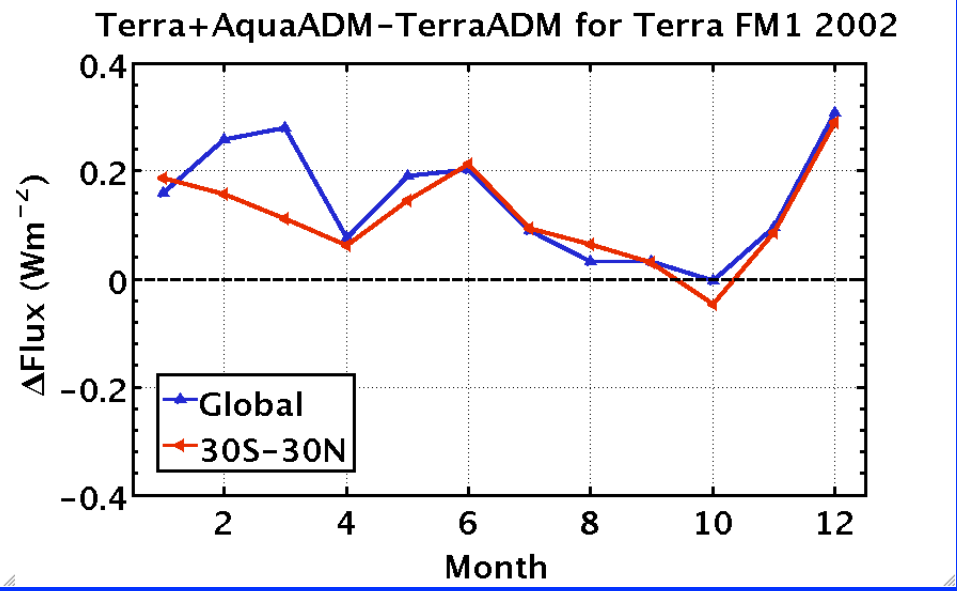
Ed4ADM: clear ocean/land/desert, cloudy ocean/land/desert

Terra ADM vs. combined Terra+Aqua ADM

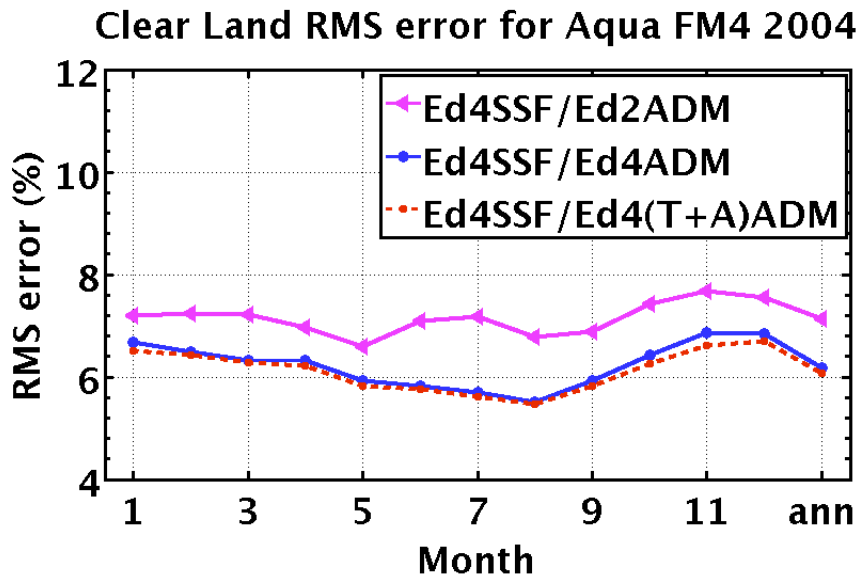


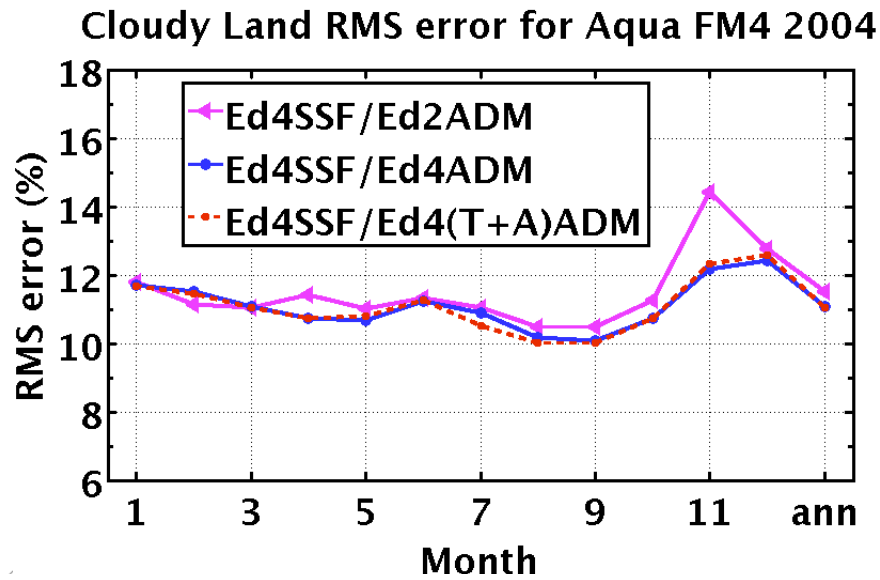


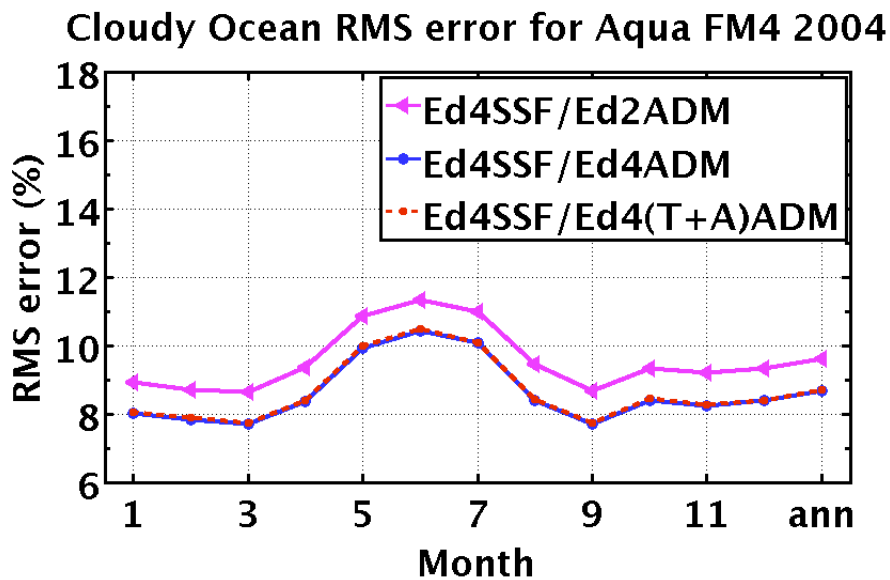


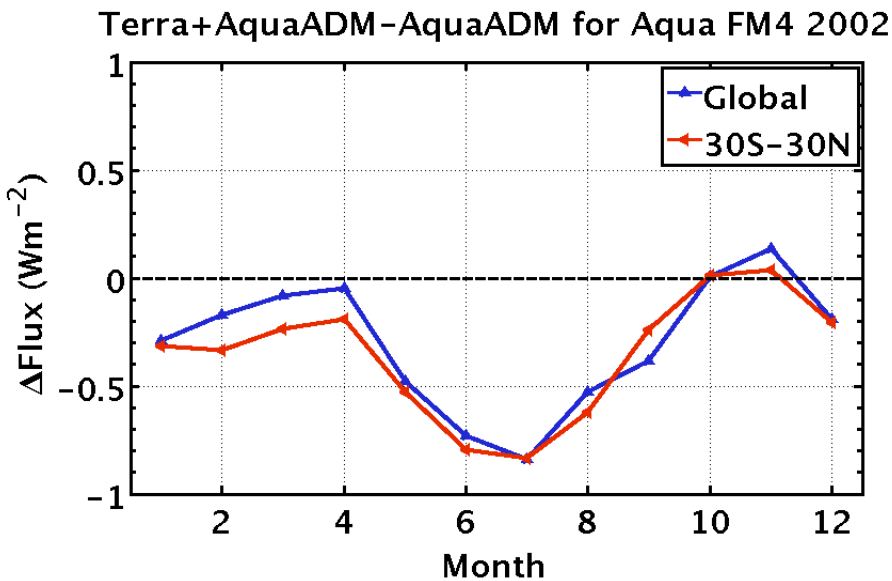


Aqua ADM vs. combined Terra+Aqua ADM









Direct integration for SW flux

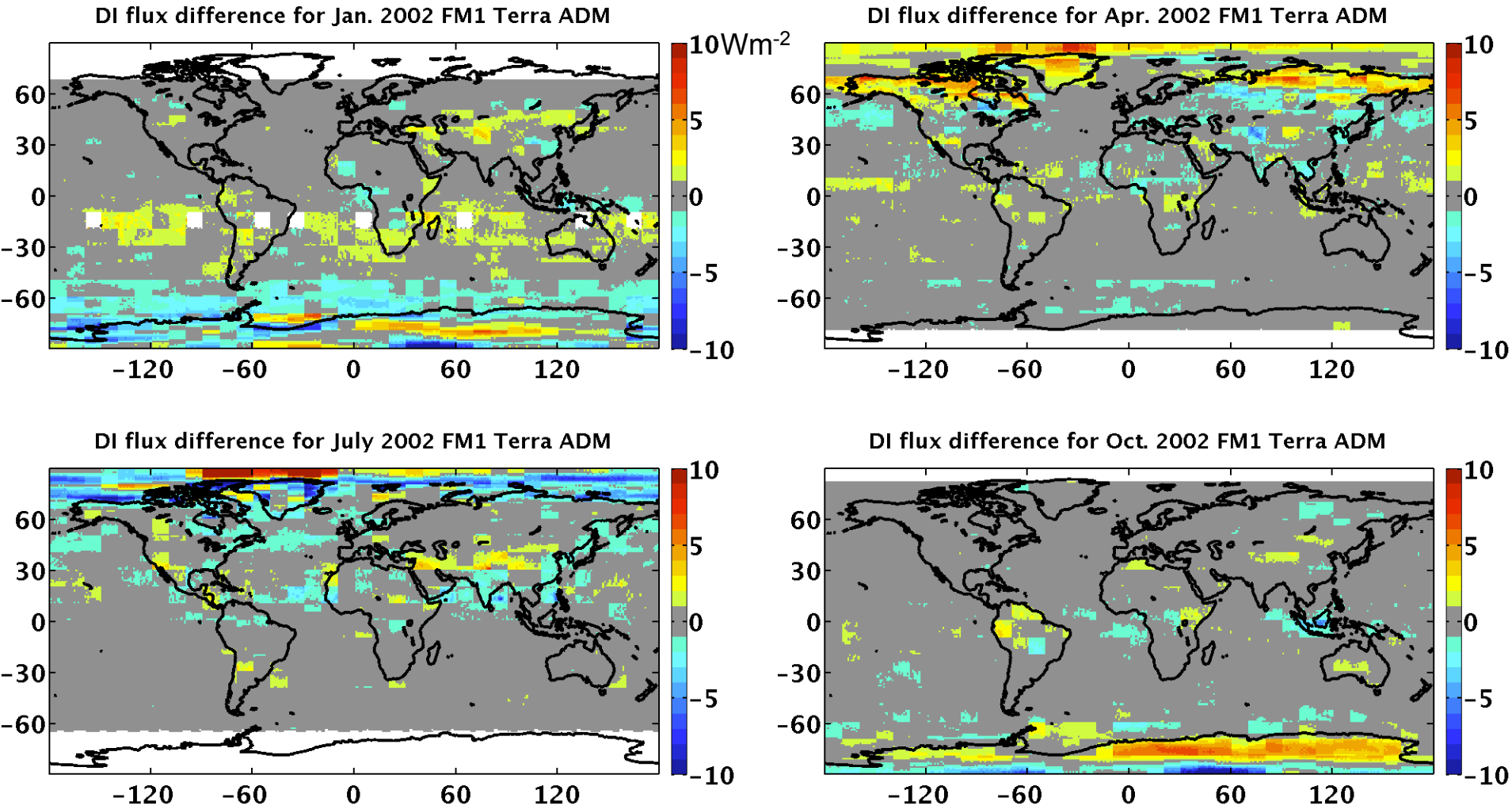
- Use observed (I_o) and ADM-predicted ($\hat{I}$) radiances to construct two sets of regional (10° X 10°) all-sky ADMs for each season

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

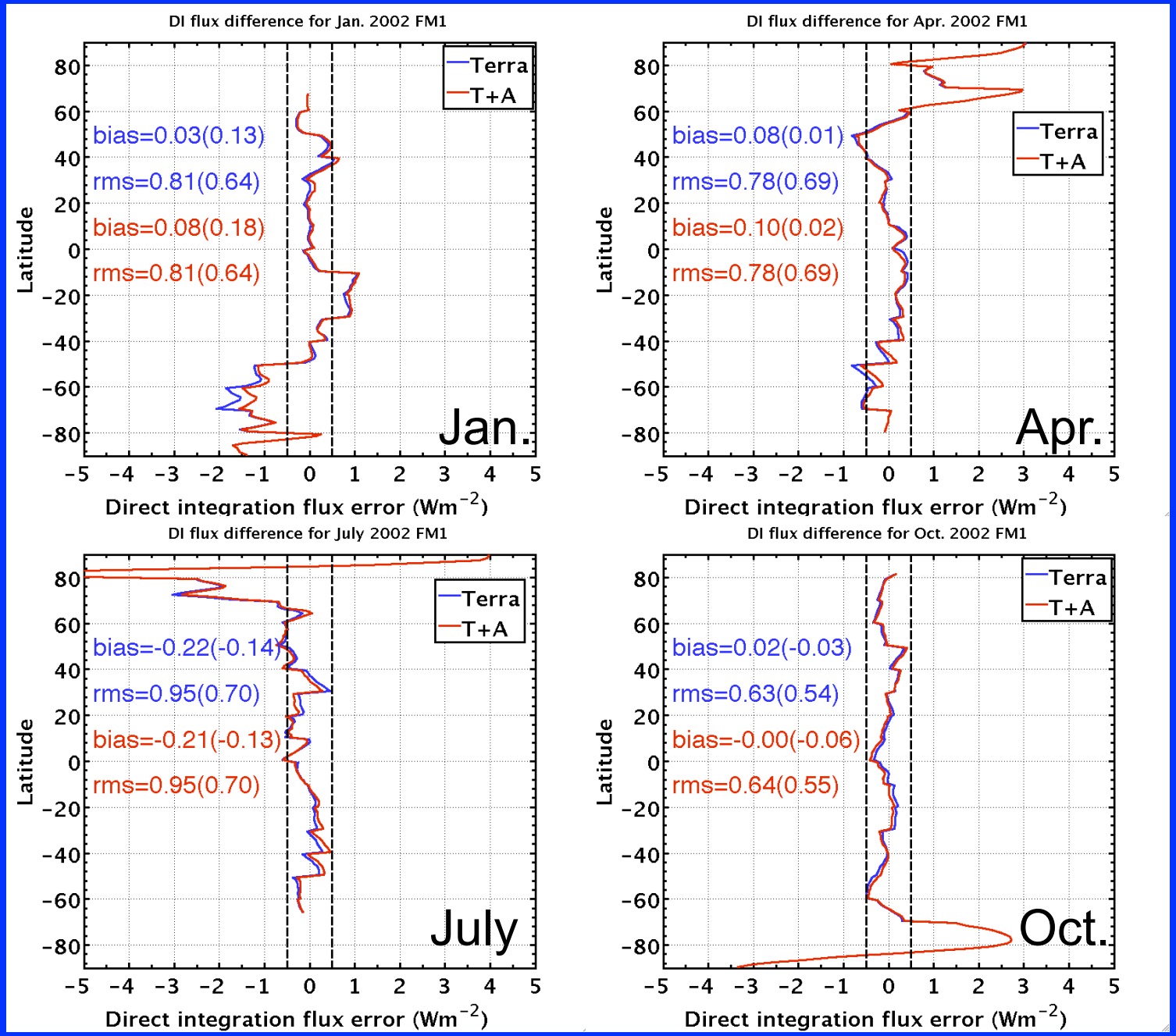
- Both sets of regional all-sky ADMs have the same sampling

- Compare fluxes derived from these two sets of ADMs

Direct integration flux error for 2002 Terra FM1 (flux from predicted radiance ADM – flux from observed radiance ADM)



Zonal mean flux error for 2002 Terra FM1



Summary

- We have worked through most scene types and have seen some improvement in the new Ed4 ADMs
- Ed4 cloud algorithm produces higher cloud fraction and more liquid clouds than Ed2 cloud algorithm
- Initial assessment indicates monthly global mean instantaneous SW flux will increase (~1.0 Wm-2) due to changes in cloud properties and ADMs. Changes in LW flux are small (~0.1 Wm-2)
- Combined Terra/Aqua ADMs (clear land, cloudy land, cloudy ocean) increase the monthly global mean fluxes from Terra (up to 0.3 Wm^{-2}), but decrease the monthly global mean fluxes from Aqua (up to 0.8 Wm^{-2}).
- Direct integration of SW indicates that zonal mean flux error is less than 0.5 Wm-2 over most none-polar regions.