Outline

- Ed4 Angular Distribution Models (ADMs)
- Cloud property differences between Ed2 and Ed4
- Flux differences due to changes in cloud properties and ADMs
- Validation
  - Shortwave direct integration
  - Longwave direct integration
  - CERES-MISR flux consistency test
  - CERES-MODIS flux consistency test
  - Ed4 cloud fraction vs. Calipso-CloudSat
- Summary and future plan

SW ADM for different scene types: Ed2 vs Ed4

Scene	Ed2	Ed4
Clear Land	1° regional monthly ADM using Ahmad&Deering 8-parameter fit for different NDVI (0.1), cosθ (0.2);	1° regional monthly ADM using modified Ross-Li 3-parameter fit for different NDVI (0.1), cosθ (0.2), and surface roughness;
Clear Ocean	Function of wind speed; correction for AOD;	Function of wind speed, AOD, and aerosol type;
Cloud Ocean	Continuous 5-parameter sigmoid function of ln(fτ) for three phases;	Update using the Ed2 method;
Cloud Land	Continuous 5-parameter sigmoid function of ln(fτ) for three phases; background albedo from clear land;	Update using the Ed2 method;

SW ADM for different scene types: Ed2 vs Ed4

Scene	Ed2	Ed4
Fresh Snow	Cloud fraction (6), snow fraction, bright/dark surface (clear 100% snow cover and ovcst), cloud optical depth (ovcst);	Clear: 1° regional monthly ADM using Ross-Li 3-para fit for different NDVI (0.1), cosθ (0.2), and surface roughness;
		Partly cloudy: surface brightness (6), and cloud fraction (4)
		Overcast: surface brightness (6), cloud phase (2), and cloud optical depth percentile bins (3)
Perm. Snow	Cloud fraction (6), bright/dark surface (clr&ovcst), cloud optical depth (ovcst);	Clear Antarctica: use MISR data to develop ADMs that account for the effect of sastrugi Clear Greenland: one ADM
		Partly cloudy: cloud fraction (4, same as Ed2)
		Overcast: cloud phase (2), and log optical depth bin (4)
Sea-Ice	Cloud fraction (6), ice fraction, bright/dark surface (clear 100% ice cover and ovcst), cloud optical depth (ovcst);	Clear: sea ice fraction (6), for 100% sea ice coverage use sea ice brightness index (3) to classify surface brightness
		Partly cloudy: cloud fraction (4), for 100% sea ice coverage use sea ice brightness index (3) to classify surface brightness
		Overcast: sea ice brightness index (5), phase (2), linear function of ln(tau)

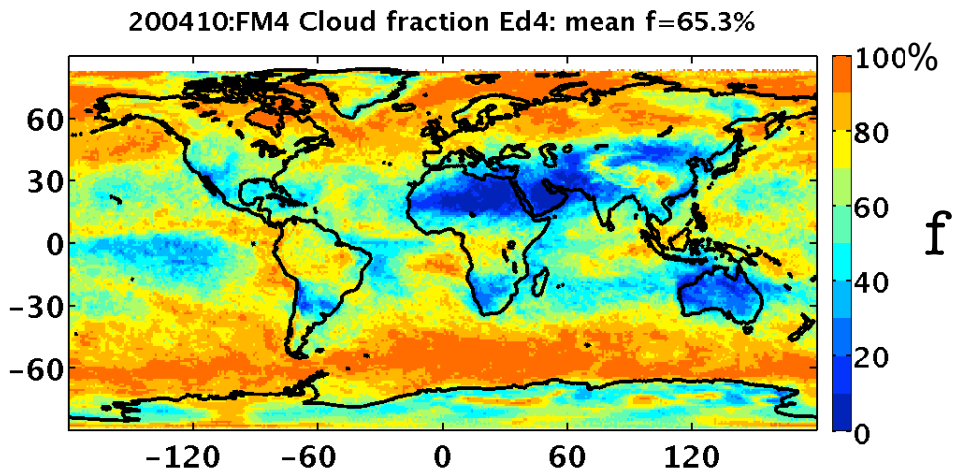
LW ADM for different scene types: Ed2 vs Ed4

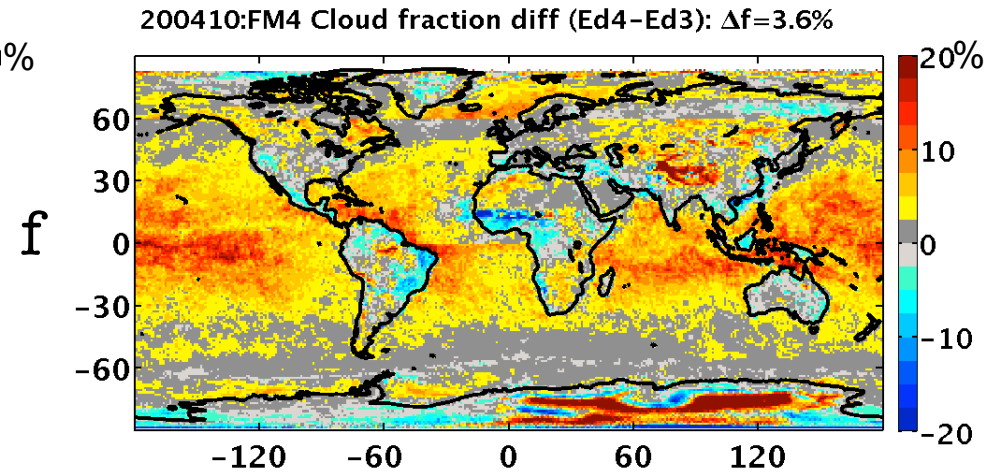
Scene	Ed2	Ed4
Clear Ocean/ Land	Discrete bins of precip. water, lapse rate, skin temp. for six surface types;	Increase skin temp. bins from 5 to 10 and add interpolation;
Cloudy Ocean/ Land	Third-order polynomial fits between radiance and 'pseudoradiance Ψ' for intervals of precip. water, cloud fraction, surface skin temp. and sfc-cld temp. difference;	Instead of a polynomial fit between pseudoradiance Ψ and radiance, the mean radiance for each 1 W m^{-2} sr^{-1} interval of Ψ is used. In addition, there are now 5 cloud fraction bins (0.1-25%, 25-50%, 50-75%, 75-99.9%, overcast).

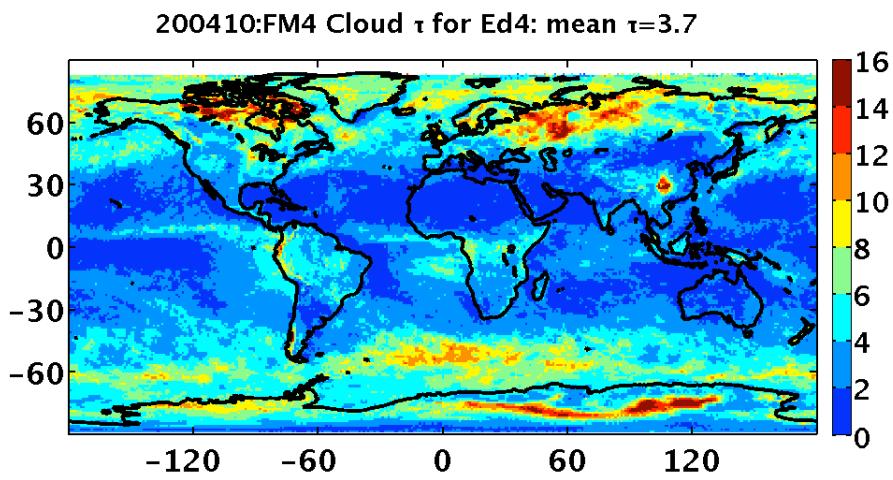
LW ADM for different scene types: Ed2 vs Ed4

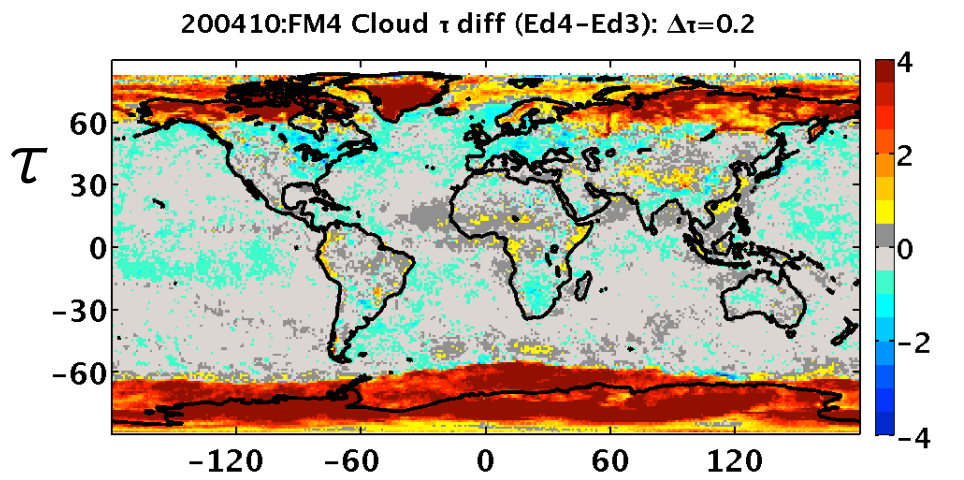
Scene	Ed2	Ed4
Fresh Snow	Discrete bins of cloud fraction, surface skin temp., and sfc-cld temp. difference;	Clr: Add Ts bins and interpolation
		Cld: Use mean radiance for each 1 W m^{-2} sr^{-1} interval of Ψ for intervals of cloud fraction, surface skin temp. and sfc-cld temp. difference;
Permanent Snow	Discrete bins of cloud fraction, surface skin temp., and sfc-cld temp. difference;	Clr: Add Ts bins and interpolation
		Cld: Use mean radiance for each 1 W m^{-2} sr^{-1} interval of Ψ for intervals of cloud fraction, surface skin temp. and sfc-cld temp. difference;
Sea-Ice	Discrete bins of cloud fraction, surface skin temp., and sfc-cld temp. difference;	Clr: Add Ts bins and interpolation
		Cld: Use mean radiance for each 1 W m^{-2} sr^{-1} interval of Ψ for intervals of cloud fraction, surface skin temp. and sfc-cld temp. difference;

Daytime cloud property difference between Ed3 and Ed4: Aqua FM4 200410



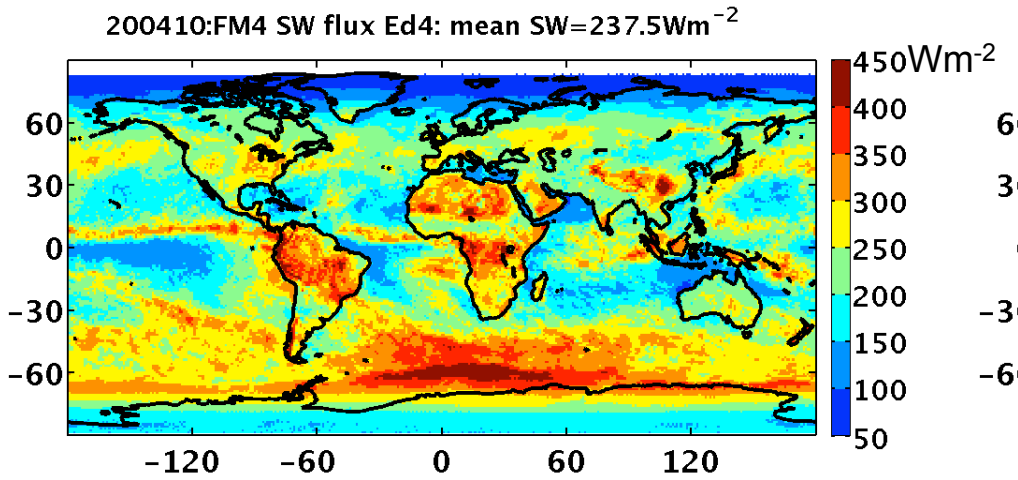




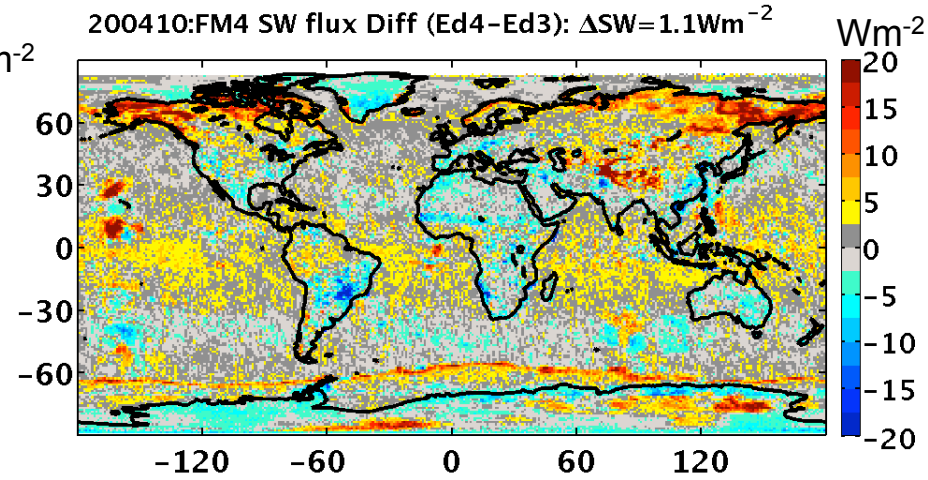


SW flux change between Ed3 and Ed4: Aqua FM4 200410

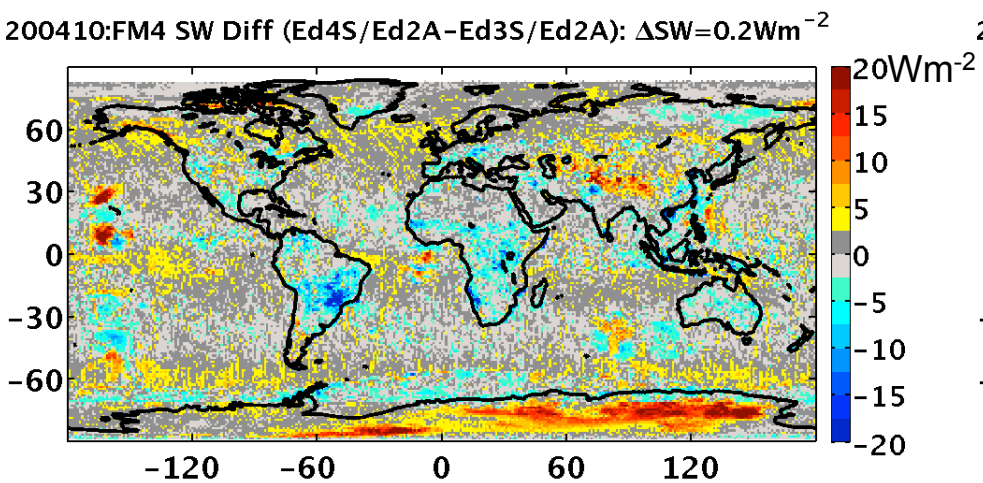
Ed4 SW flux



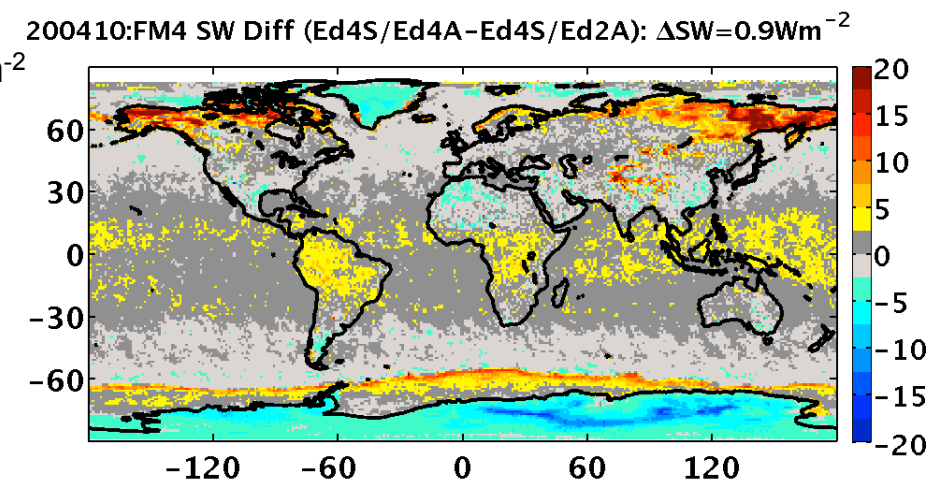
SW flux diff: Ed4-Ed3



Flux change due to cloud change

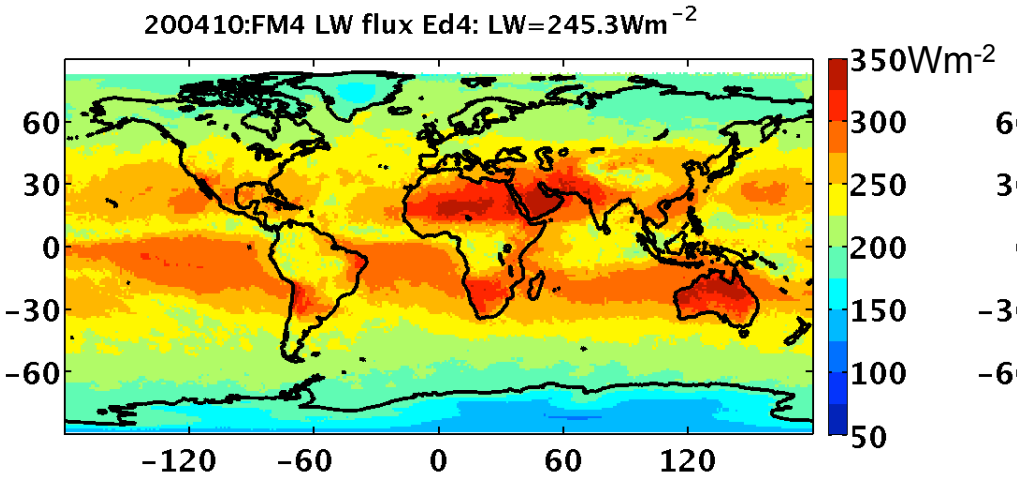


Flux change due to ADM change

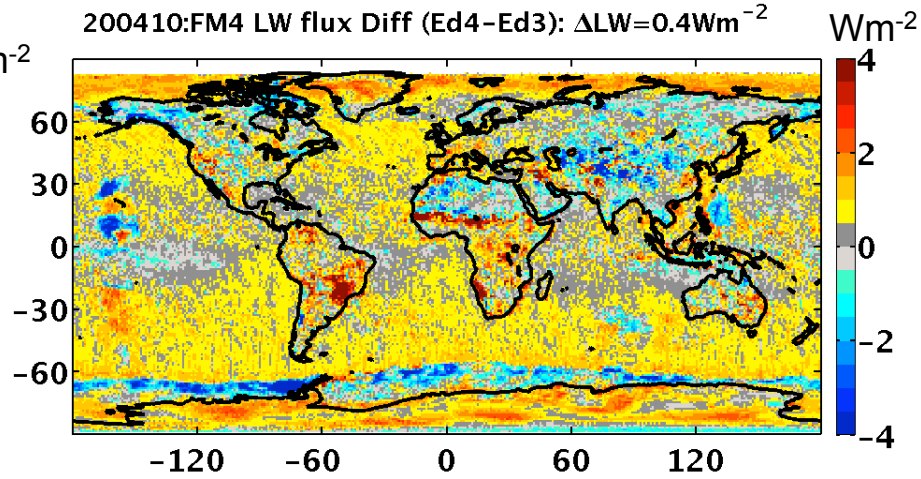


Daytime LW flux change between Ed3 and Ed4:Aqua FM4 200410

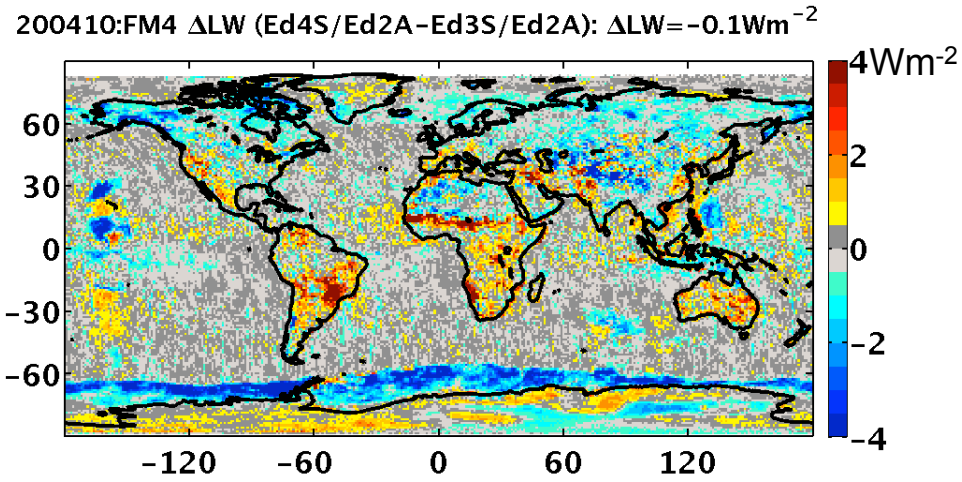
Ed4 LW flux



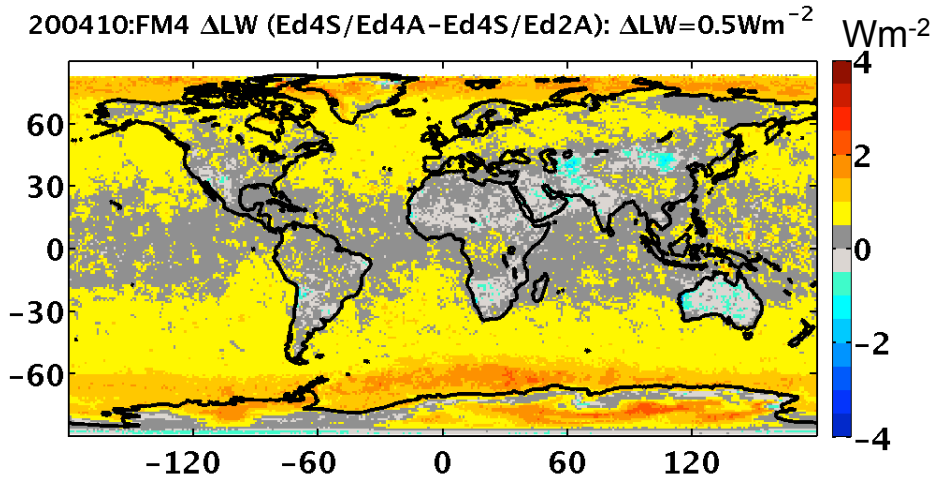
LW flux diff: Ed4-Ed3



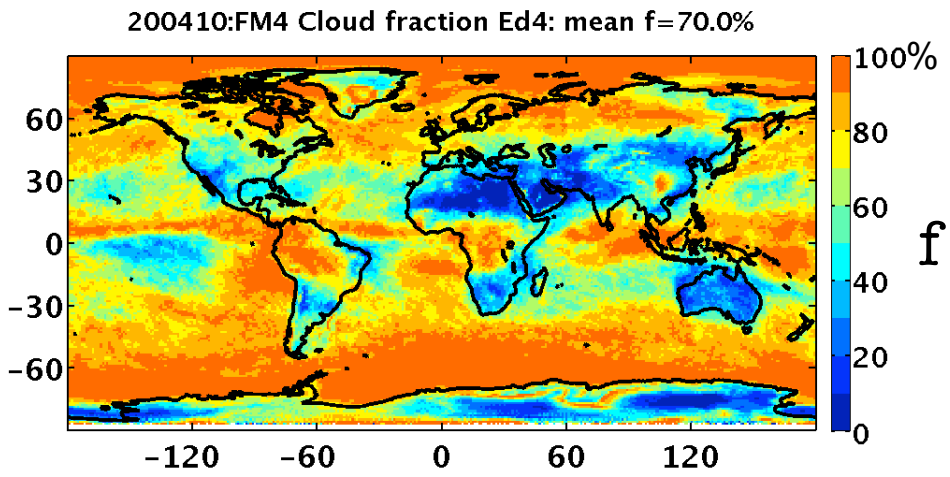
Flux change due to cloud change



Flux change due to ADM change



Nighttime cloud property difference between Ed3 and Ed4: Aqua FM4 200410



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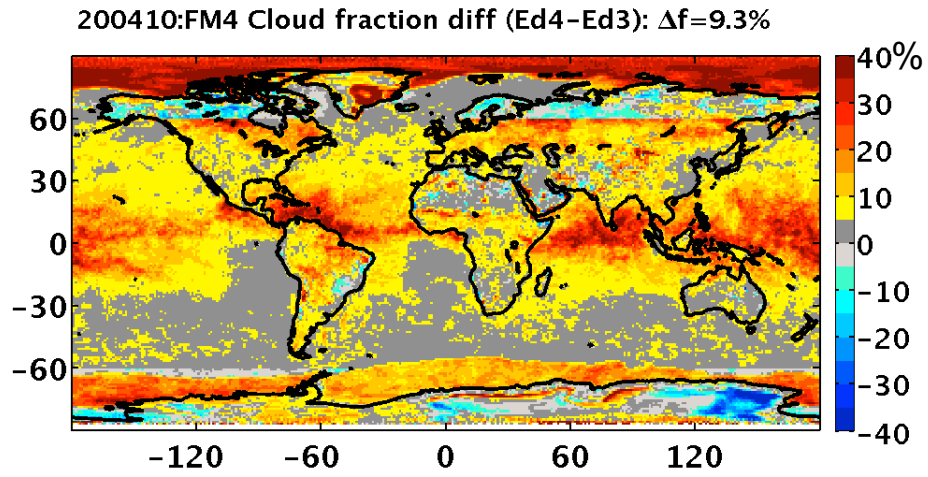
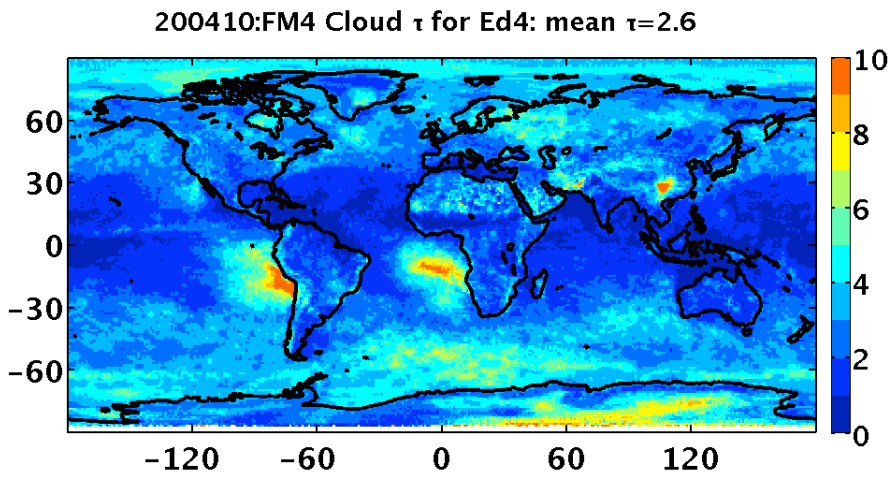
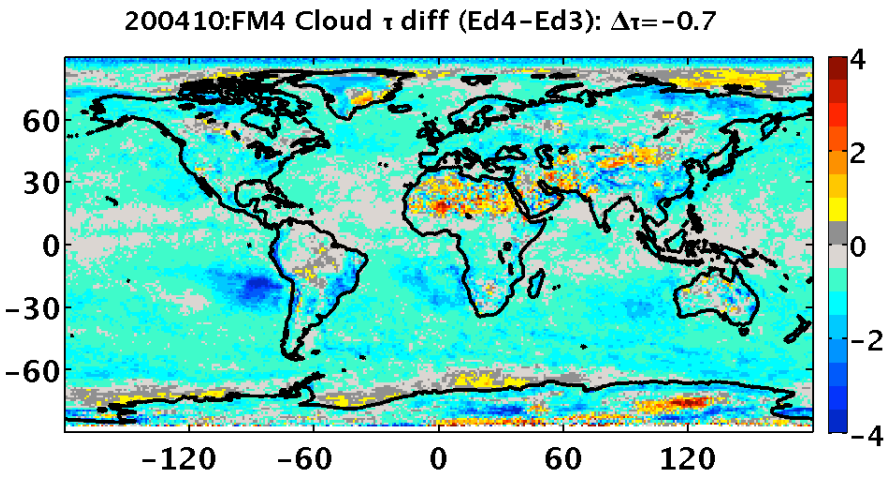


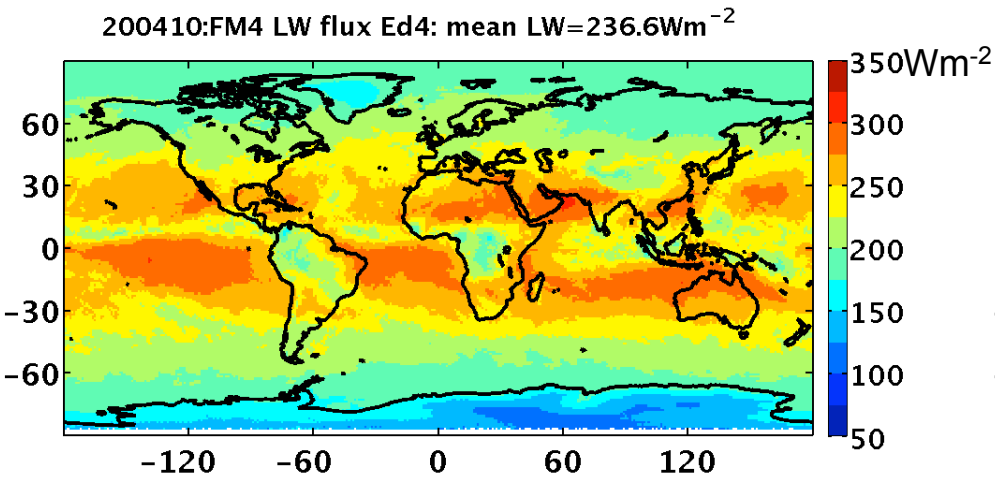


τ

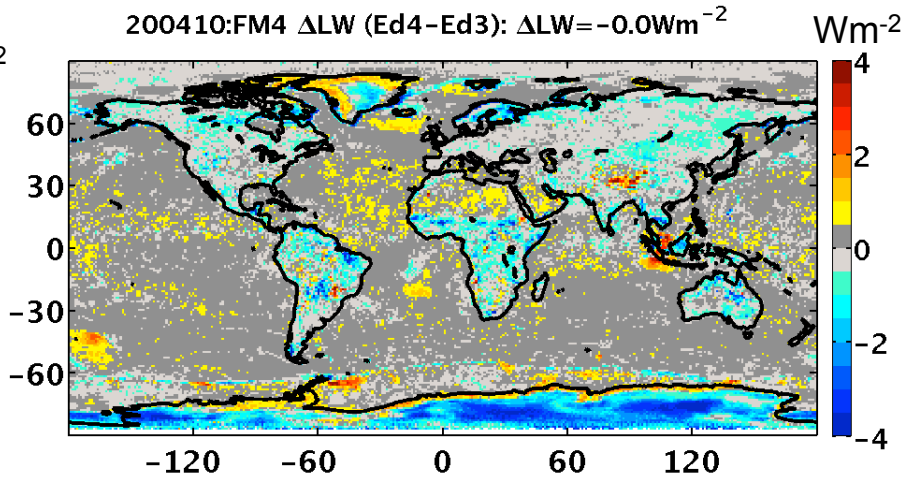


Nighttime LW flux change between Ed3 and Ed4: Aqua FM4 200410

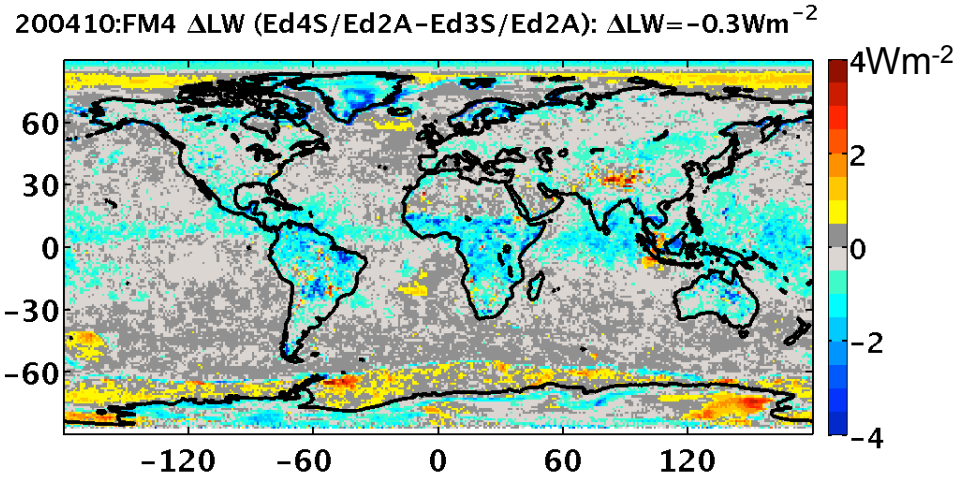
Ed4 LW flux



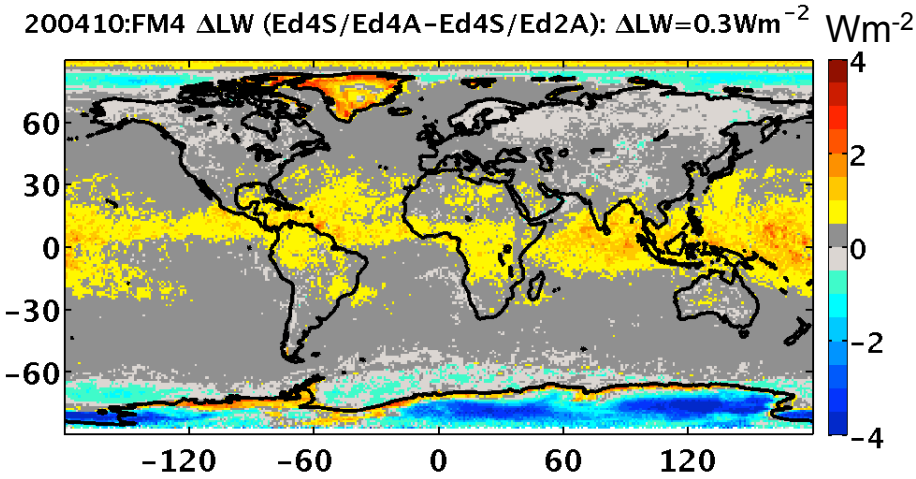
LW flux diff: Ed4-Ed3



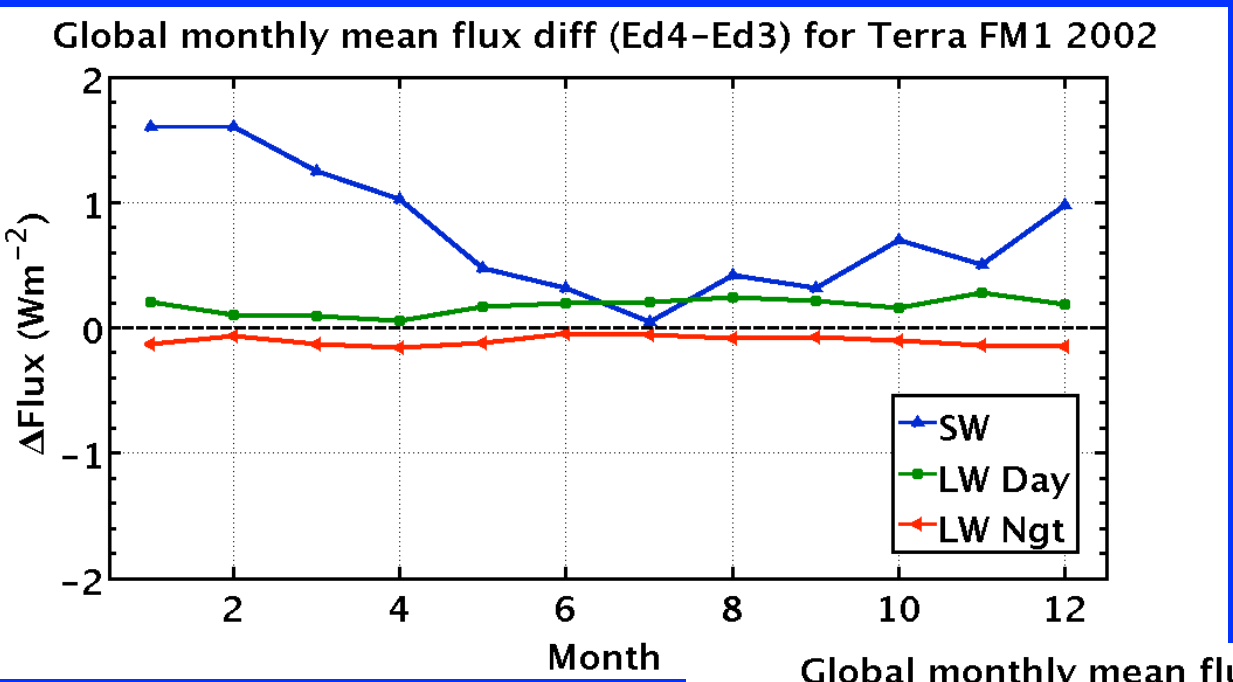
Flux change due to cloud change



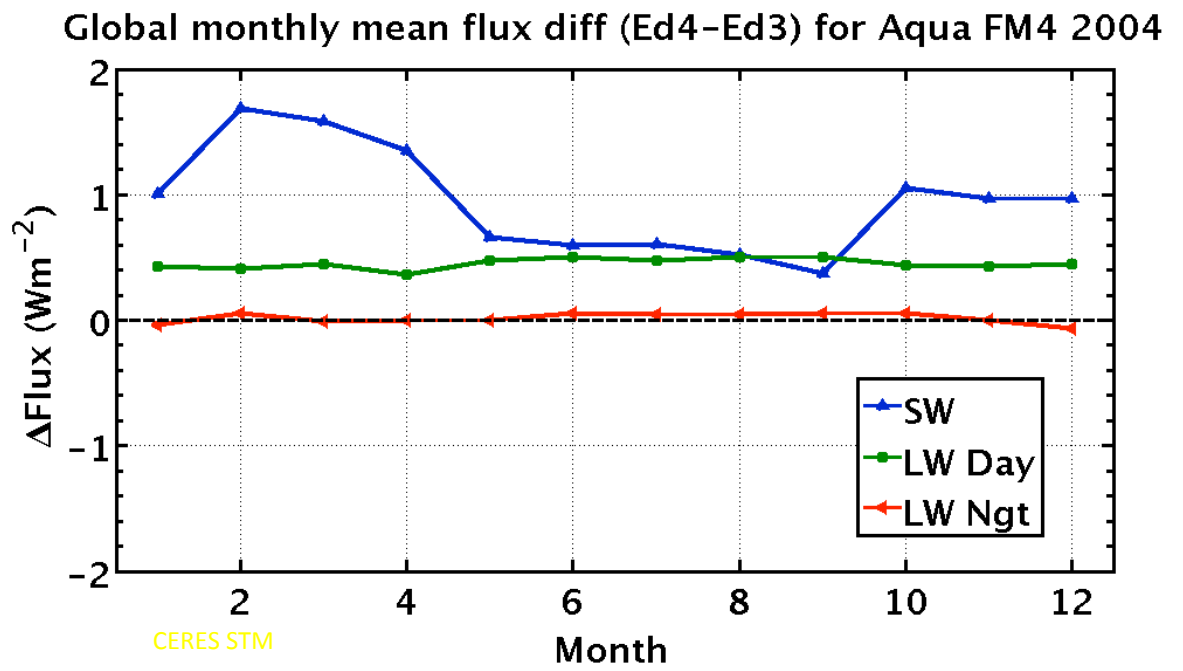
Flux change due to ADM change



Global monthly mean flux difference between Ed4 and Ed3



- Annual mean SW flux increases 0.8 Wm^{-2}
- Annual mean daytime LW flux increases 0.2 Wm^{-2}
- Annual mean nighttime LW flux decreases 0.1 Wm^{-2}

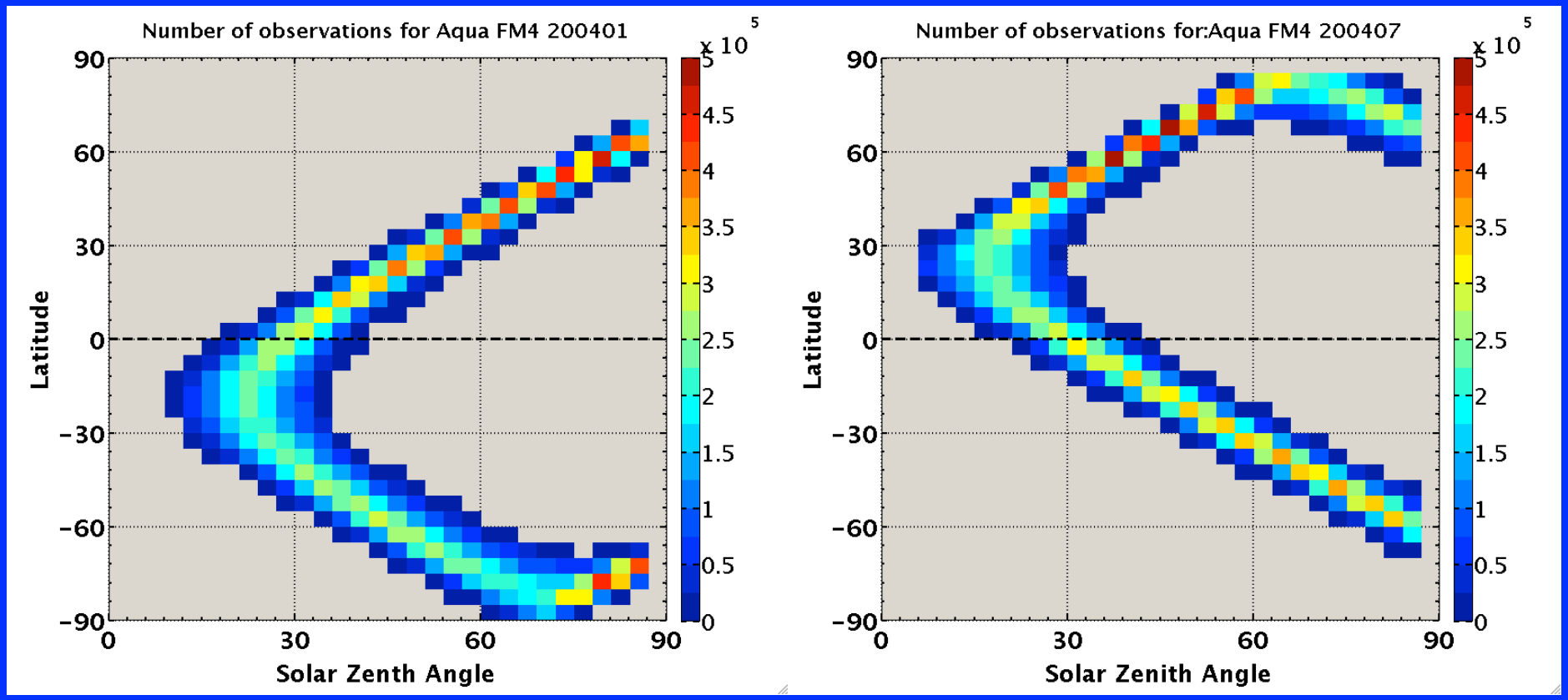


- Annual mean SW flux increases 1 Wm^{-2}
- Annual mean daytime LW flux increases 0.4 Wm^{-2}
- Annual mean nighttime LW flux is the same

Validation

Direct integration

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



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

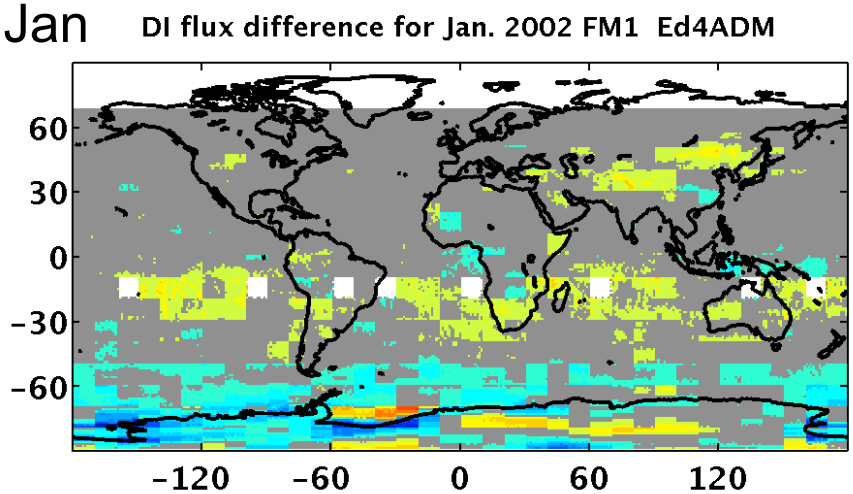
- Compare fluxes derived from these two sets of ADMs

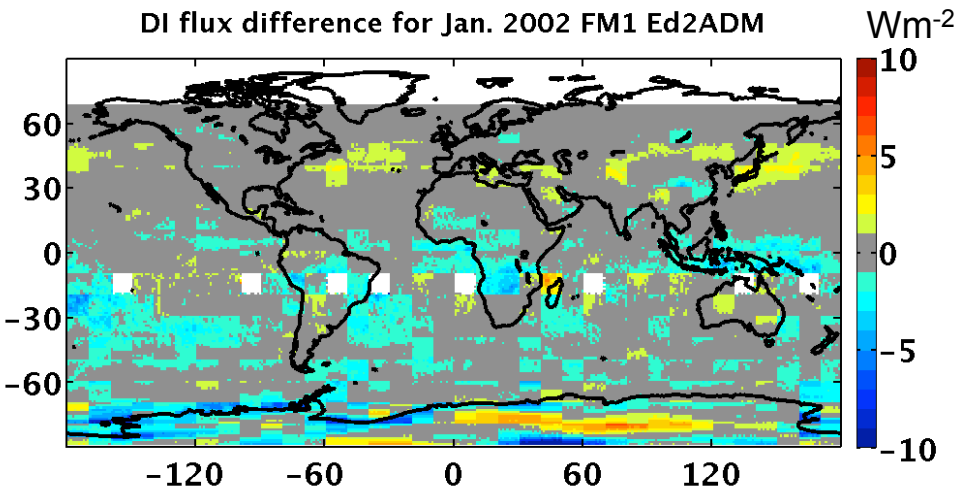
Direct integration SW flux error for 2002 Terra FM1 (flux from predicted radiance ADM – flux from observed radiance ADM)

Direction integration using Ed4ADM

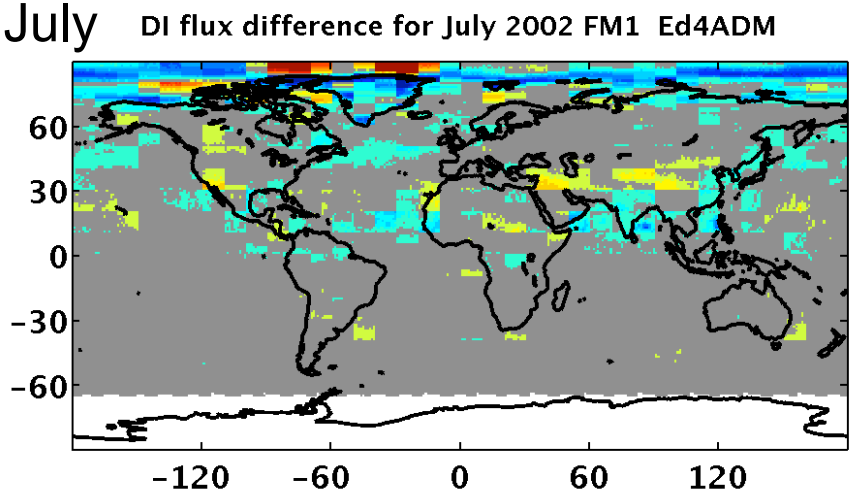
Direction integration using Ed2ADM

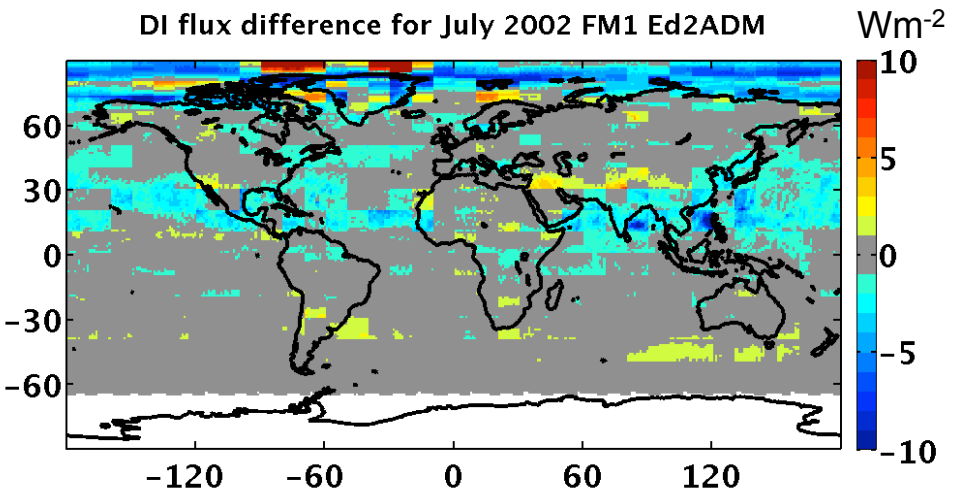
Jan



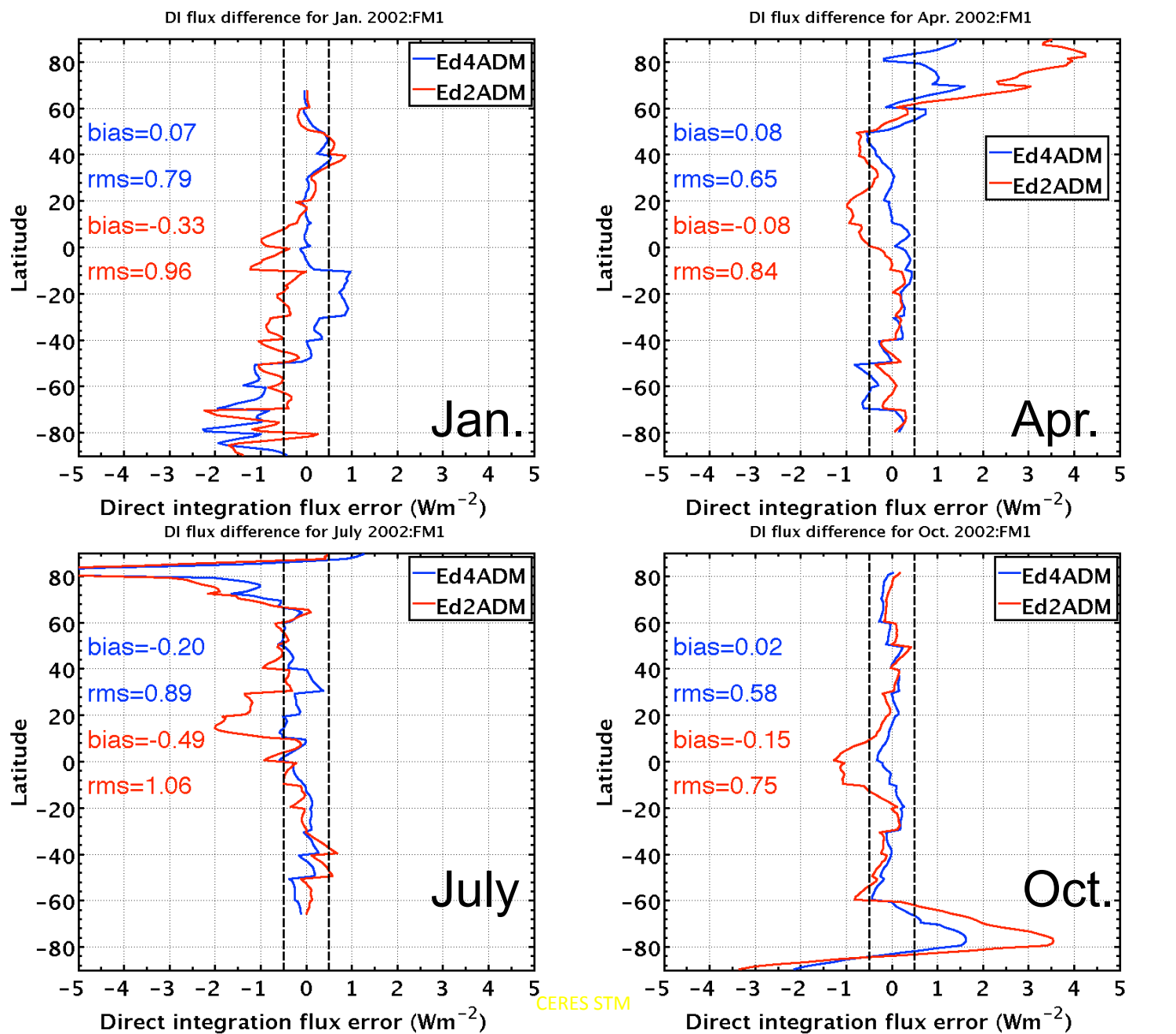


July





Zonal mean SW flux error for 2002 Terra FM1

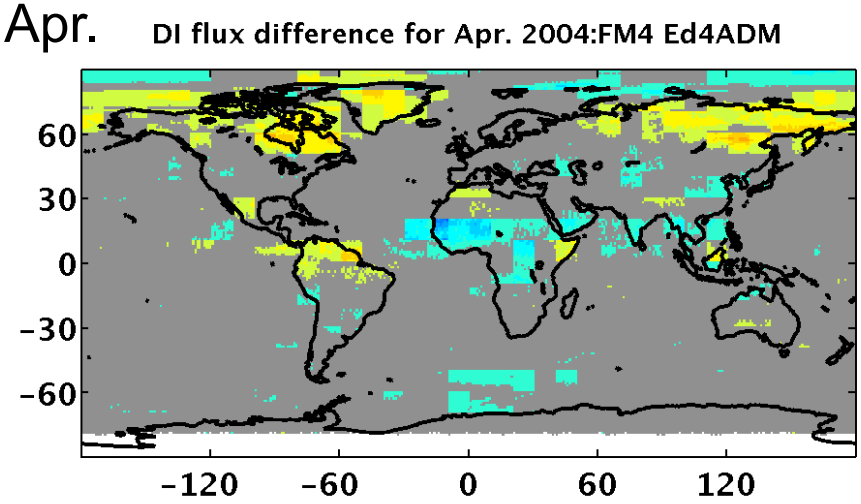


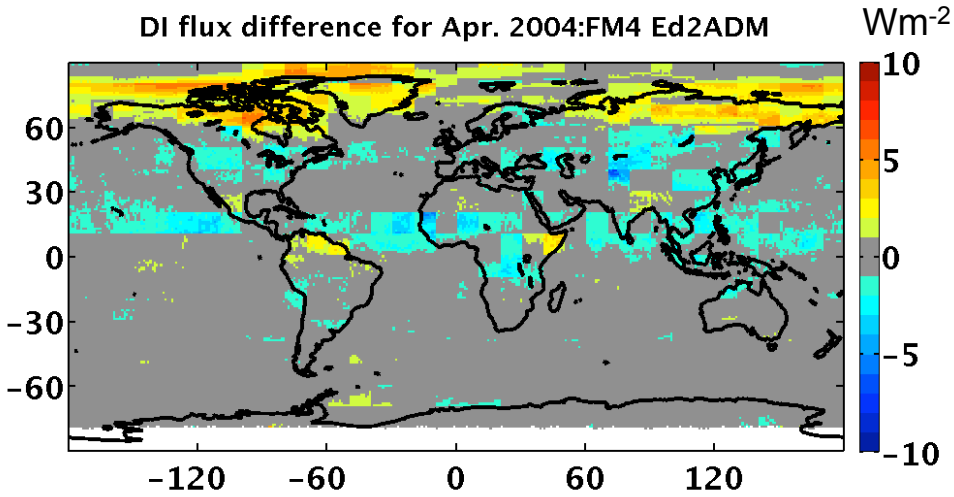
Direct integration SW flux error for 2004 Aqua FM4 (flux from predicted radiance ADM – flux from observed radiance ADM)

Direction integration using Ed4ADM

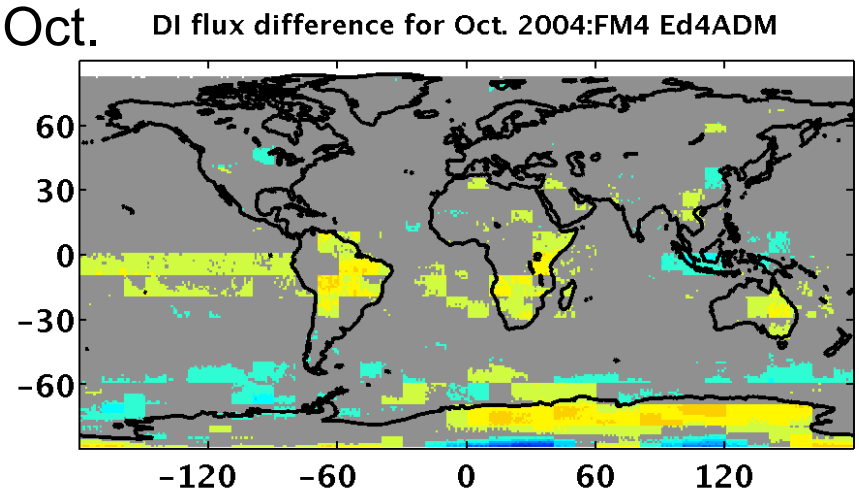
Direction integration using Ed2ADM

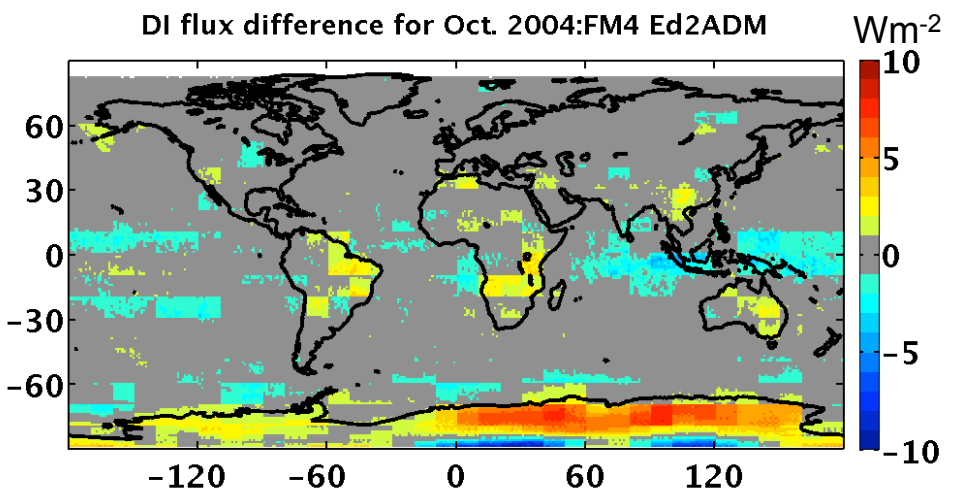
Apr.



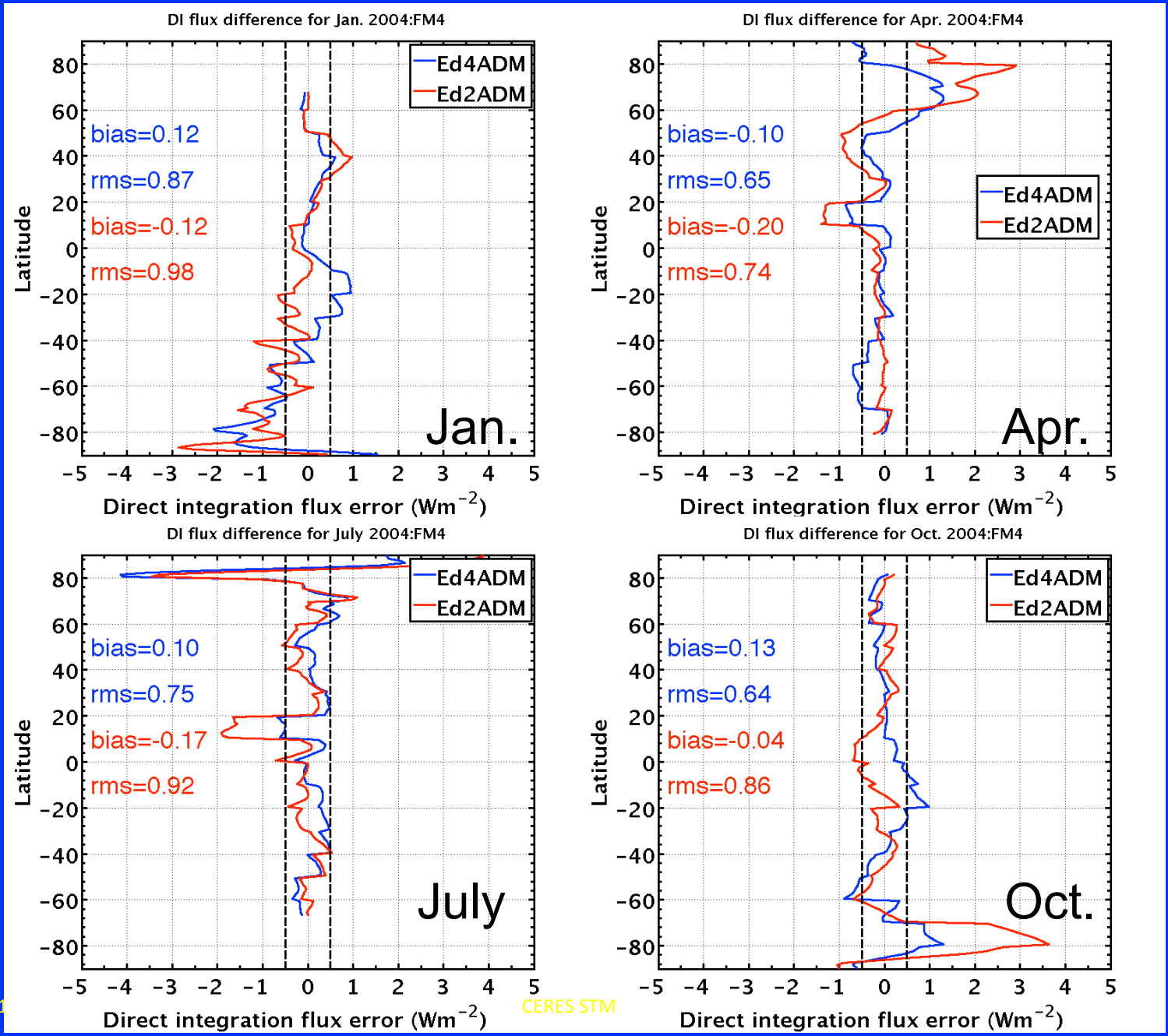


Oct.





Zonal mean SW flux error for 2004 Aqua FM4



Direct integration for LW

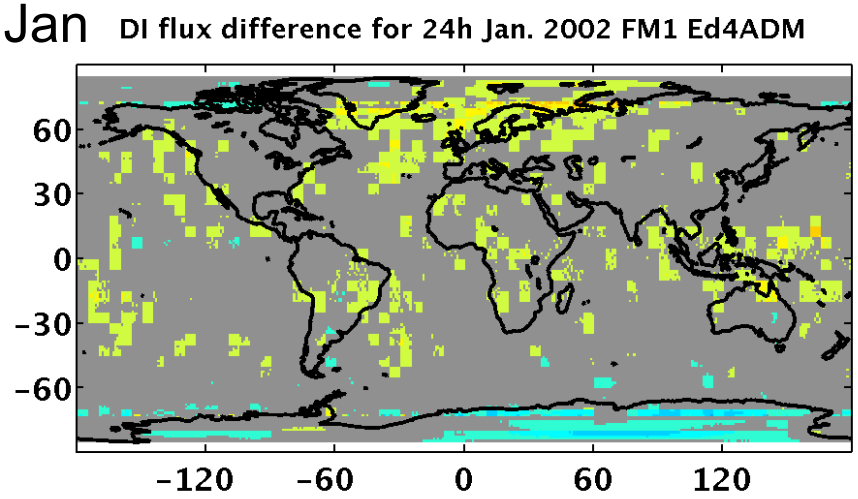
- LW flux is a weak function of solar zenith angle
- Use standard direct integration for LW flux
- Done separately for daytime and nighttime observations
- Weight the daytime and nighttime flux error by fraction of daylight at each latitude for each month to derive the 24h-averaged flux error

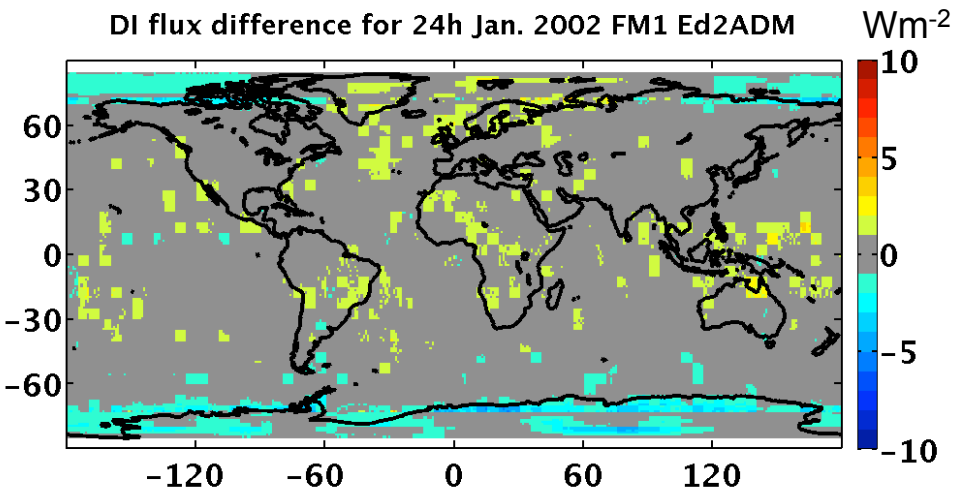
Direct integration LW flux error for 2002 Terra FM1 (ADM flux – DI flux)

Direction integration using Ed4ADM

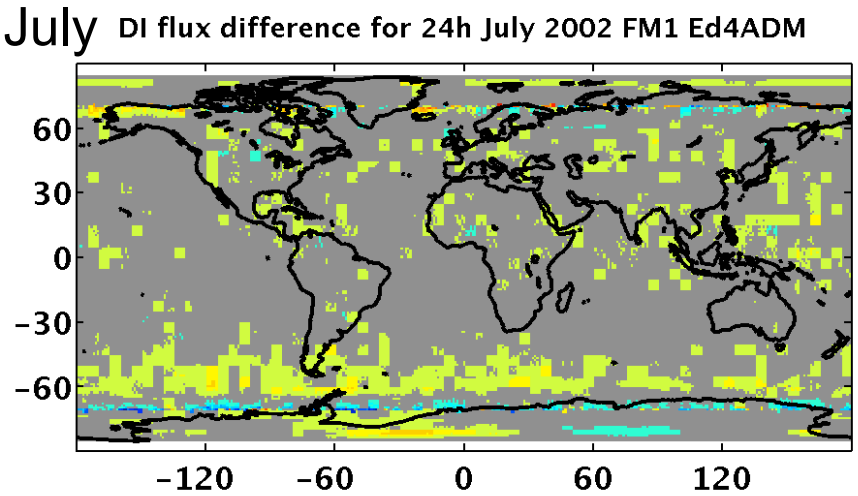
Direction integration using Ed2ADM

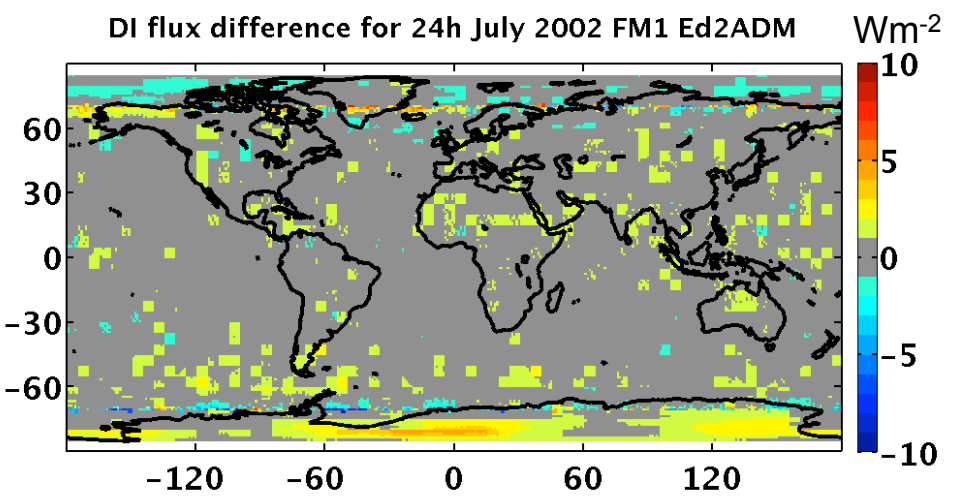
Jan



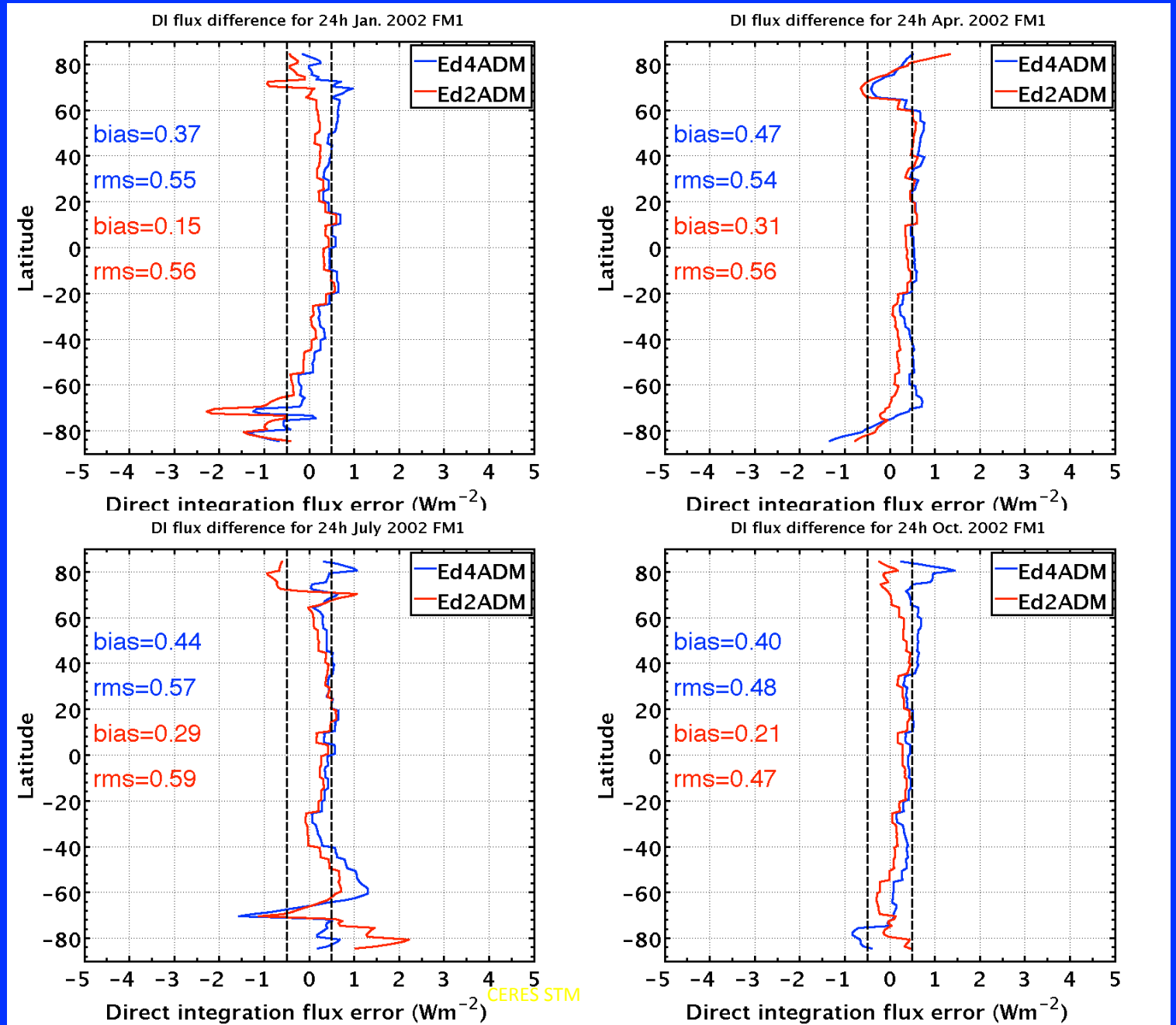


July





Zonal mean LW flux error for 2002 Terra FM1

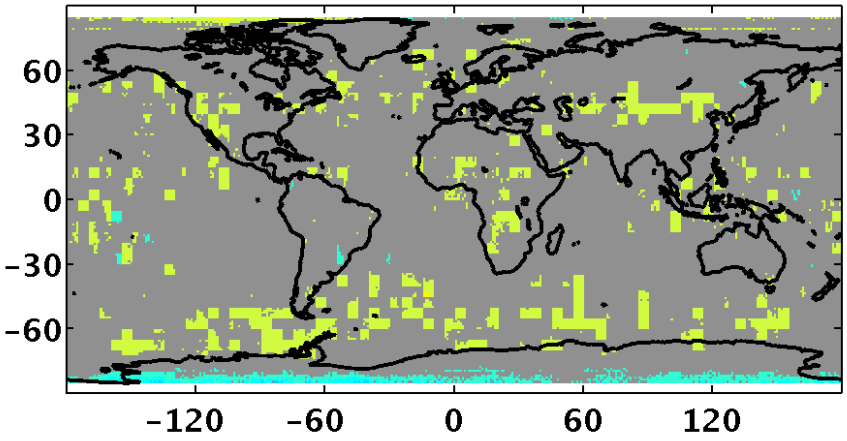


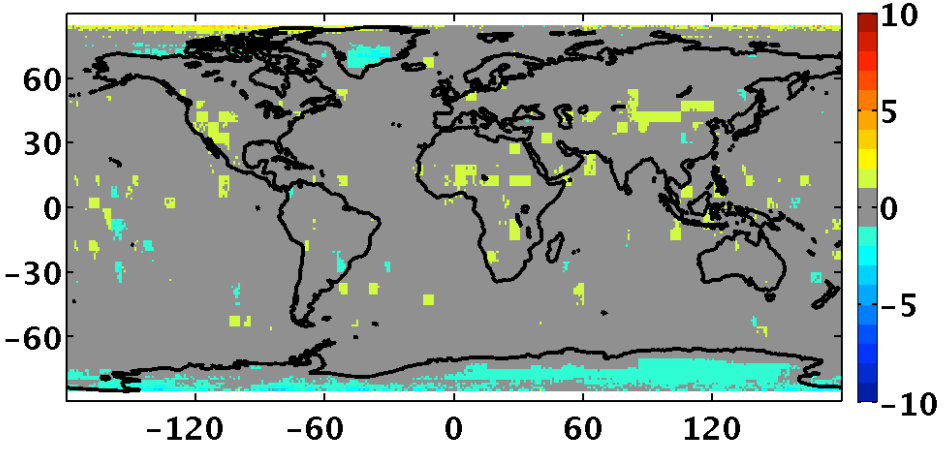
Direct integration LW flux error for 2004 Aqua FM4 (ADM flux – DI flux)

Direction integration using Ed4ADM

Direction integration using Ed2ADM

Apr.





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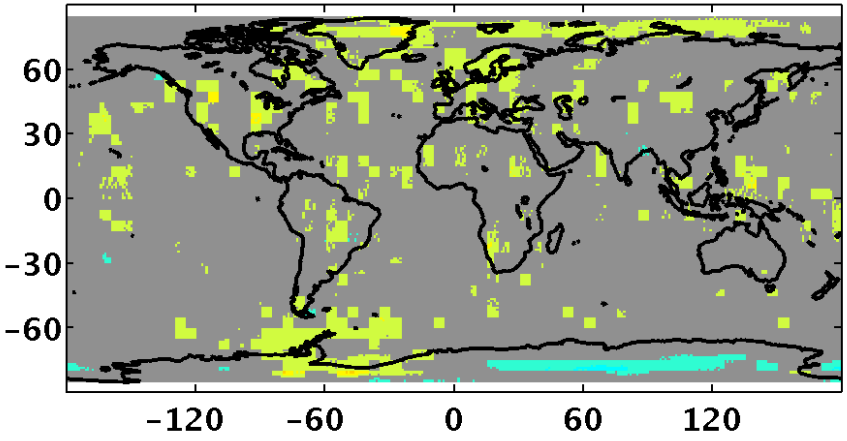
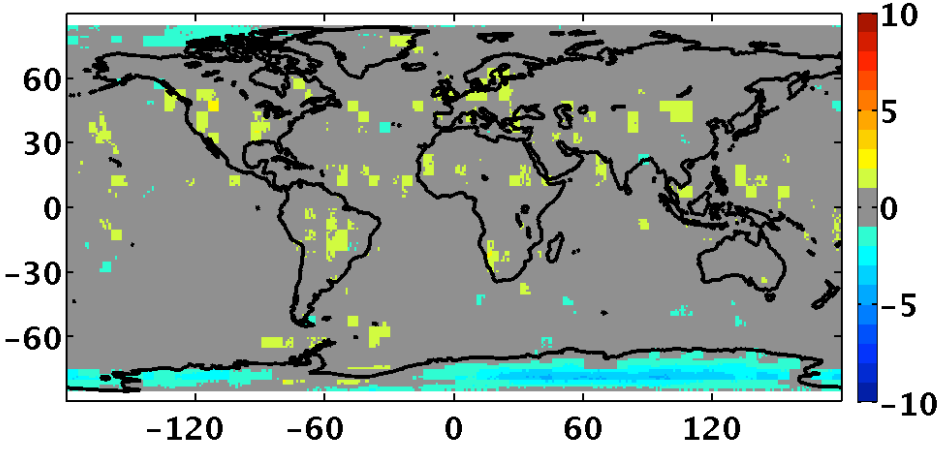
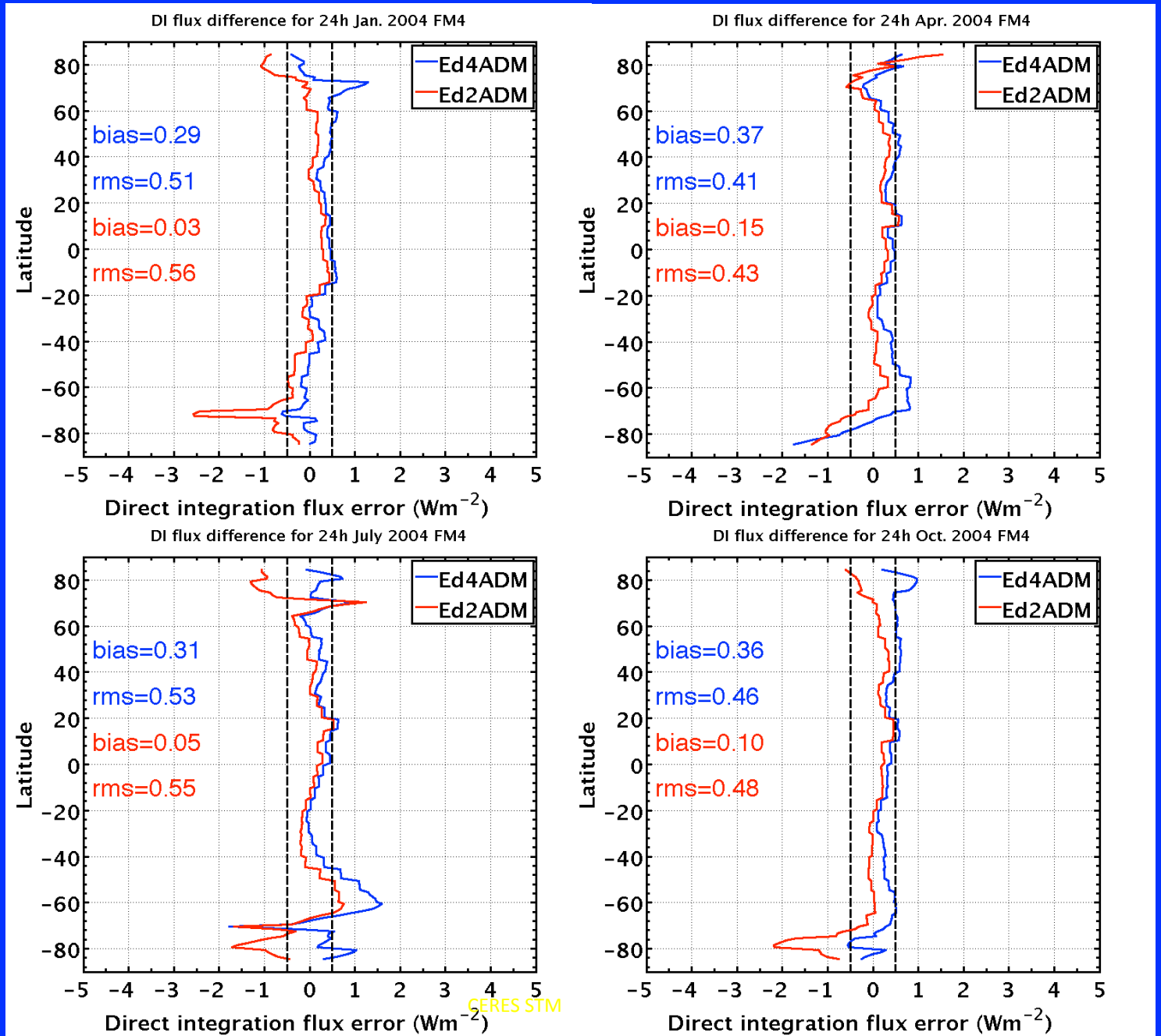


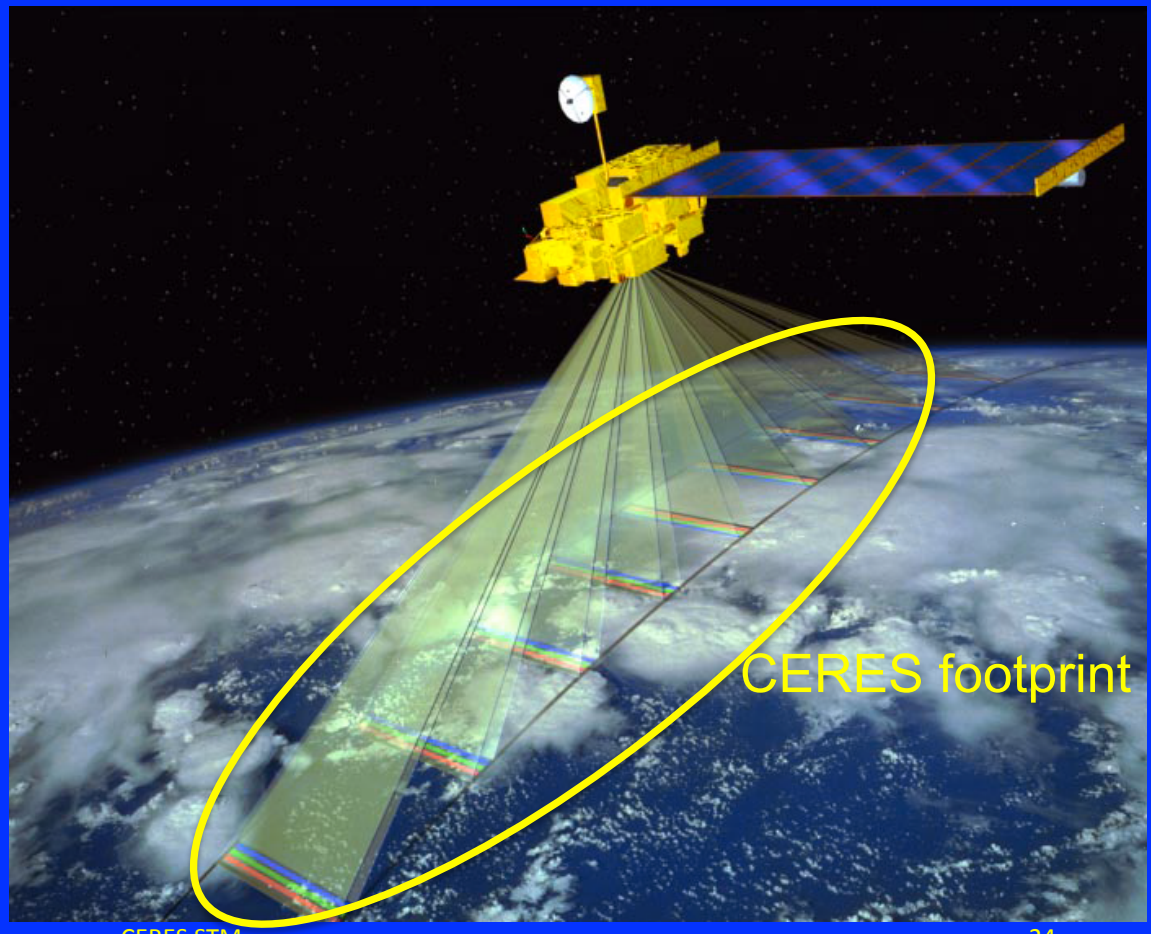


Zonal mean LW flux error for 2004 Aqua FM4



Flux consistency from nine MISR cameras

- MISR instrument has 4 spectral bands;
- MISR instrument has 9 cameras;
- Average MISR pixel-level radiances into along-track CERES footprint using CERES convolution algorithm.



CERES-MISR consistency test

- Convert narrow band MISR radiance to broadband radiance for each MISR camera

$$I_{sw}^{ms} = c_0 + c_1 I_{0.45} + c_2 I_{0.67} + c_3 I_{0.87}$$

- Apply CERES ADM to MISR broadband radiances to derive fluxes from different MISR cameras (j)
- Calculate flux consistency in the MISR fluxes using sample standard deviation :

$$s_i = \sqrt{\frac{\sum_{j=1}^{n} (F_{ij}^{sw} - \overline{F_i^{sw}})^2}{n-1}}$$

CERES-MISR consistency test

- Calculate the overall relative consistency of the TOA fluxes for a population of CERES footprint:

$$\overline{CV_T} = \left(\frac{\sqrt{\frac{1}{M}\sum_{i=1}^{M} s_i^2}}{\frac{1}{M}\sum_{i=1}^{M} \overline{F_i^{sw}}} \right) \times 100\%$$

- Determine narrow-to-broadband regression error
- Calculate the flux consistency error from ADM

$$CV_{ADM} = \sqrt{CV_T^2 - CV_{NB}^2}$$

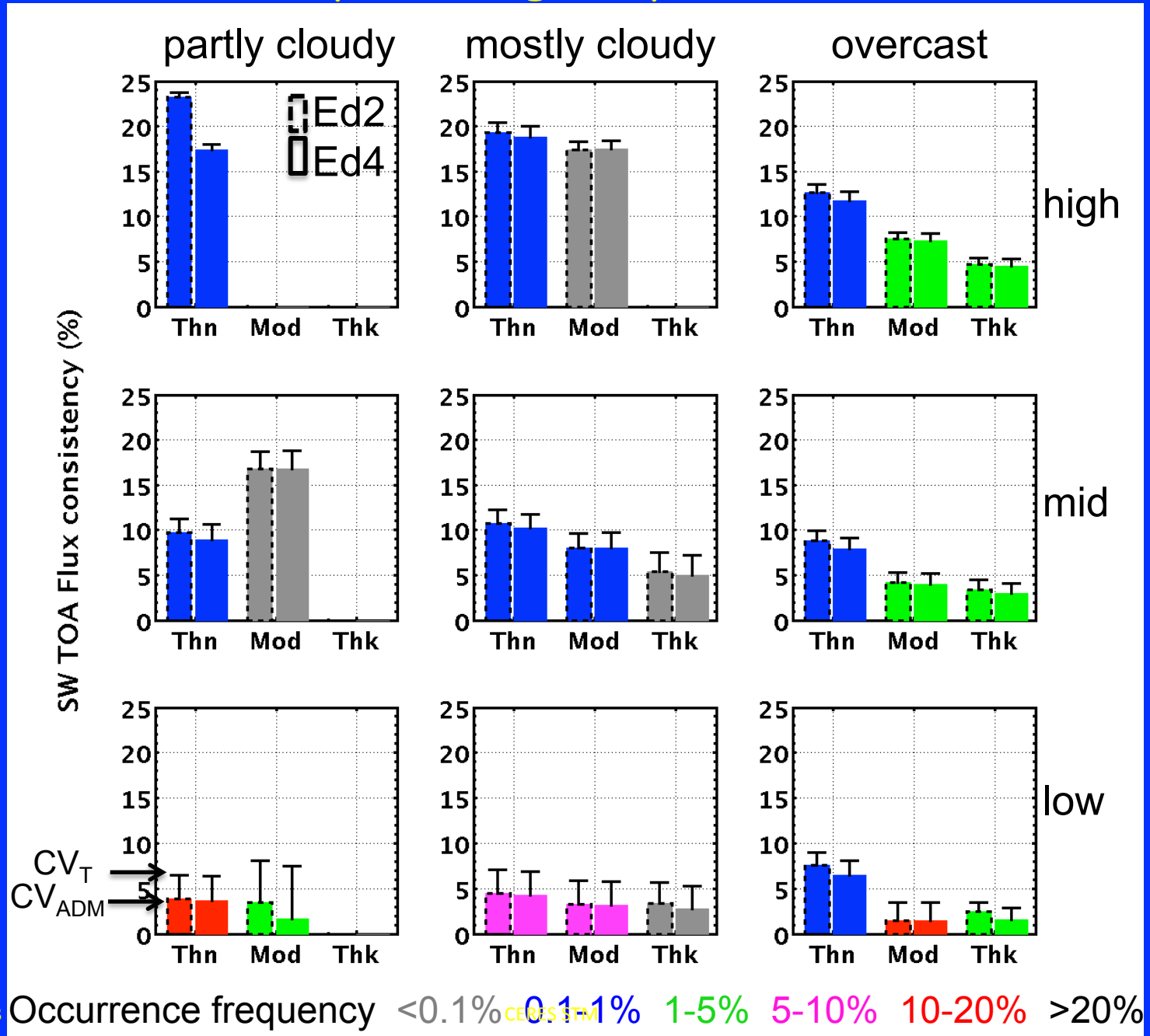
- 137 alongtrack days used

Cloud layer classification

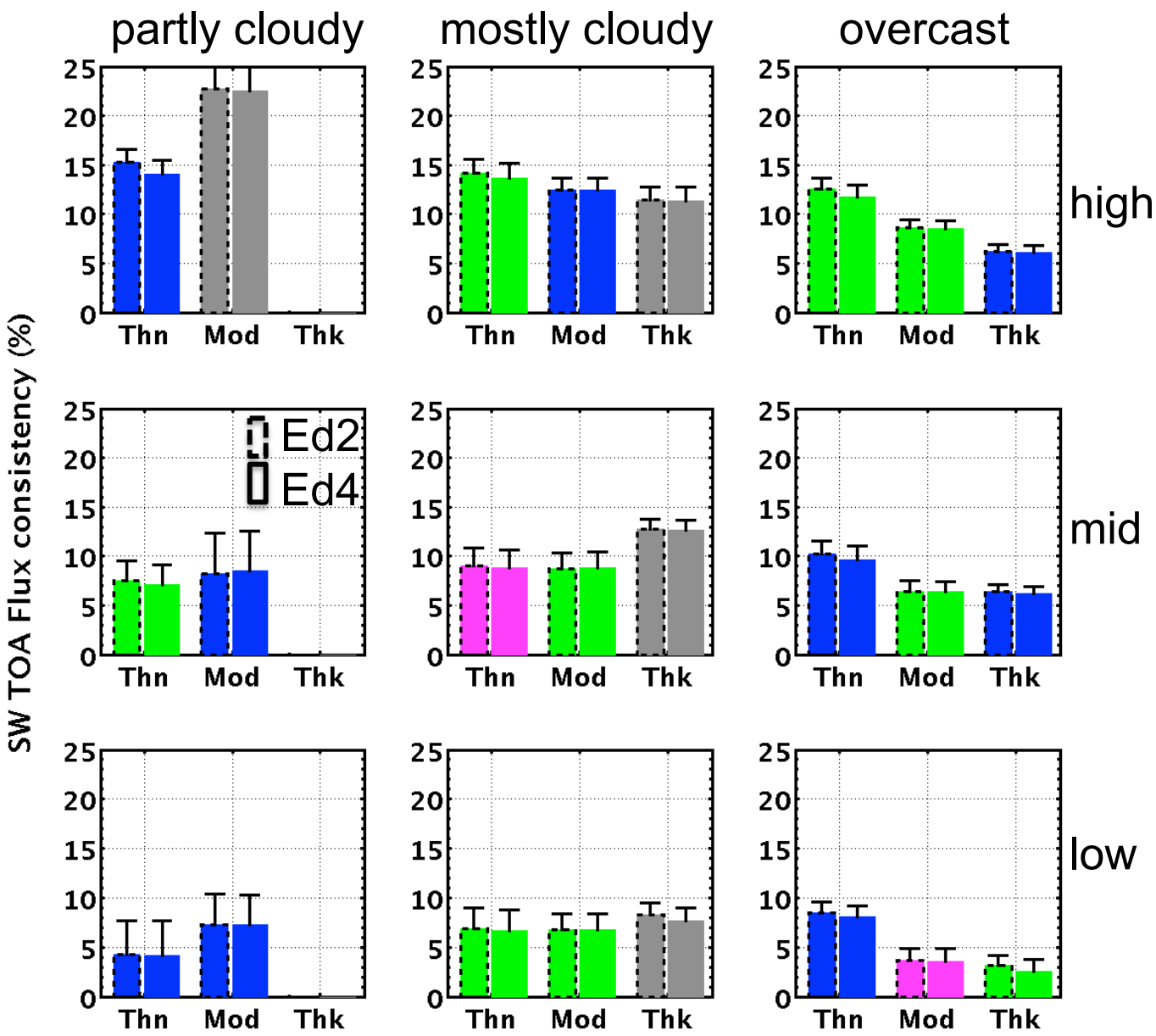
	Partly cloudy			Mostly cloudy			Overcast		
High	19	20	21	22	23	24	25	26	27
Mid	10	11	12	13	14	15	16	17	18
Low	1	2	3	4	5	6	7	8	9
	Thin	Mod	Thick	Thin	Mod	Thick	Thin	Mod	Thick

Partly cloudy: CF =0.1-40%	High: EP<440 hPa	Thin: $\tau < 3.35$
Mostly cloudy: CF=40-99%	Mid: EP = 440-680 hPa	Mod: $\tau = 3.35 - 22.63$
Overcast: CF=99-100%	Low: EP > 680 hPa	Thick: $\tau > 22.63$

Flux consistency for single layer clouds over ocean



Flux consistency for multi-layer clouds over ocean

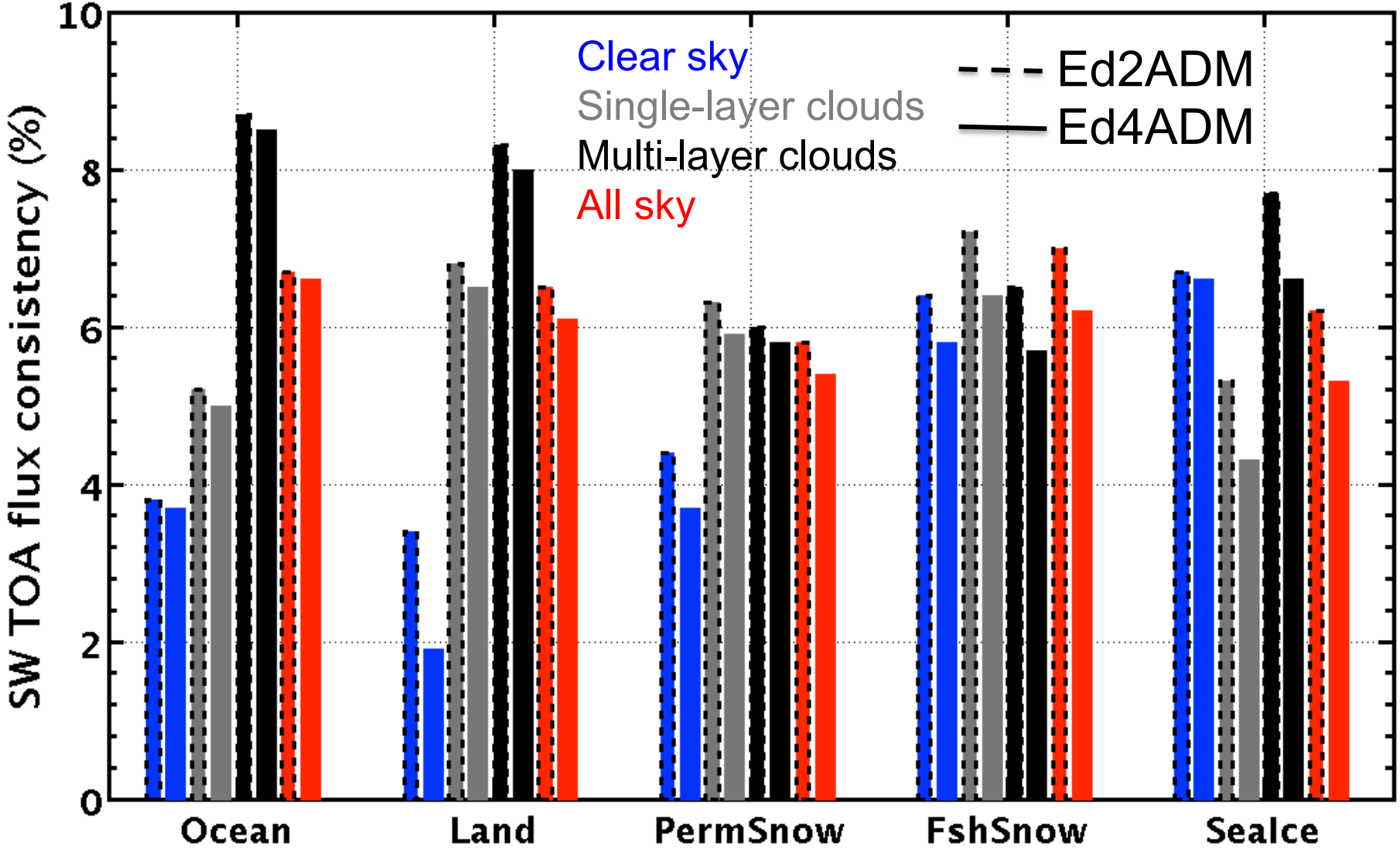


Occurrence frequency <0.1% 0.1-1% 1-5% 5-10% 10-20% >20%

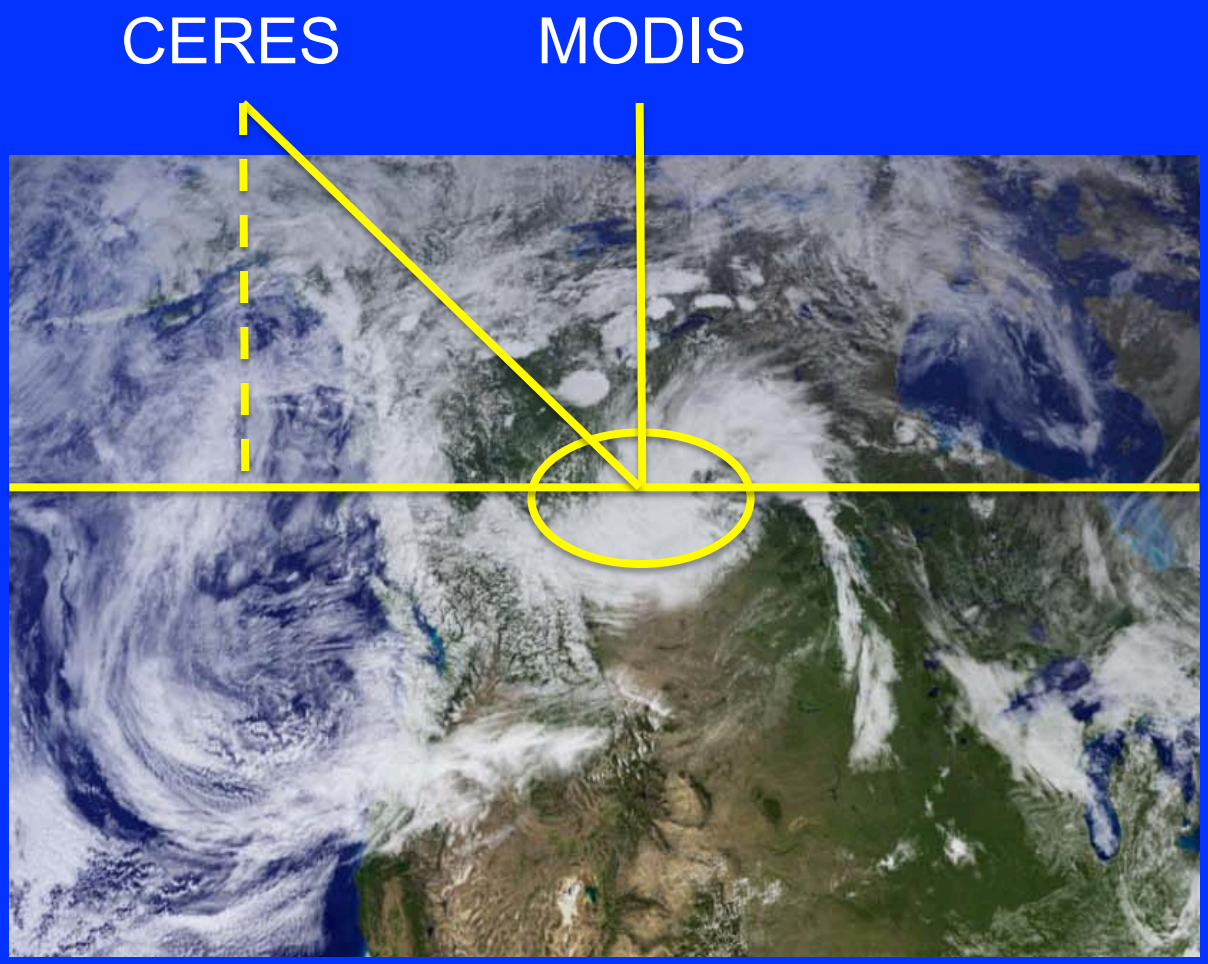
Ed4ADM improves the MISR flux consistency over ocean for clear, cloudy, and all-sky conditions

	Clear Ocean		Single Layer		Multilayer		All sky	
	Ed4ADM	Ed2ADM	Ed4ADM	Ed2ADM	Ed4ADM	Ed2ADM	Ed4ADM	Ed2ADM
cv_{adm}(%)	3.7	3.8	5.0	5.2	8.5	8.7	6.6	6.7
Cv_{adm}(Wm^{-2})	3.2	3.3	13.2	13.7	20.2	20.6	16.3	16.7
Population (%)	2.3	2.3	56.4	56.4	41.3	41.3	100	100

Ed4ADM improve the MISR flux consistency



CERES-MODIS instantaneous TOA flux consistency test



CERES-MODIS instantaneous TOA flux consistency test

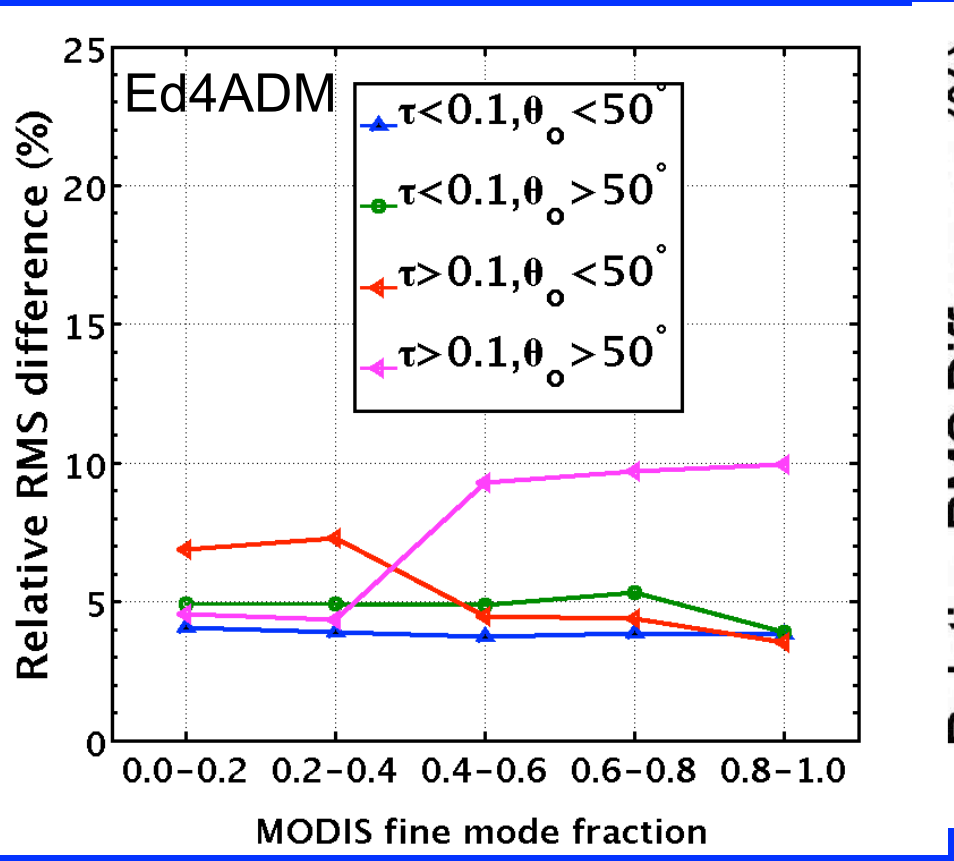
- Convert MODIS narrow band radiance to broad band radiance

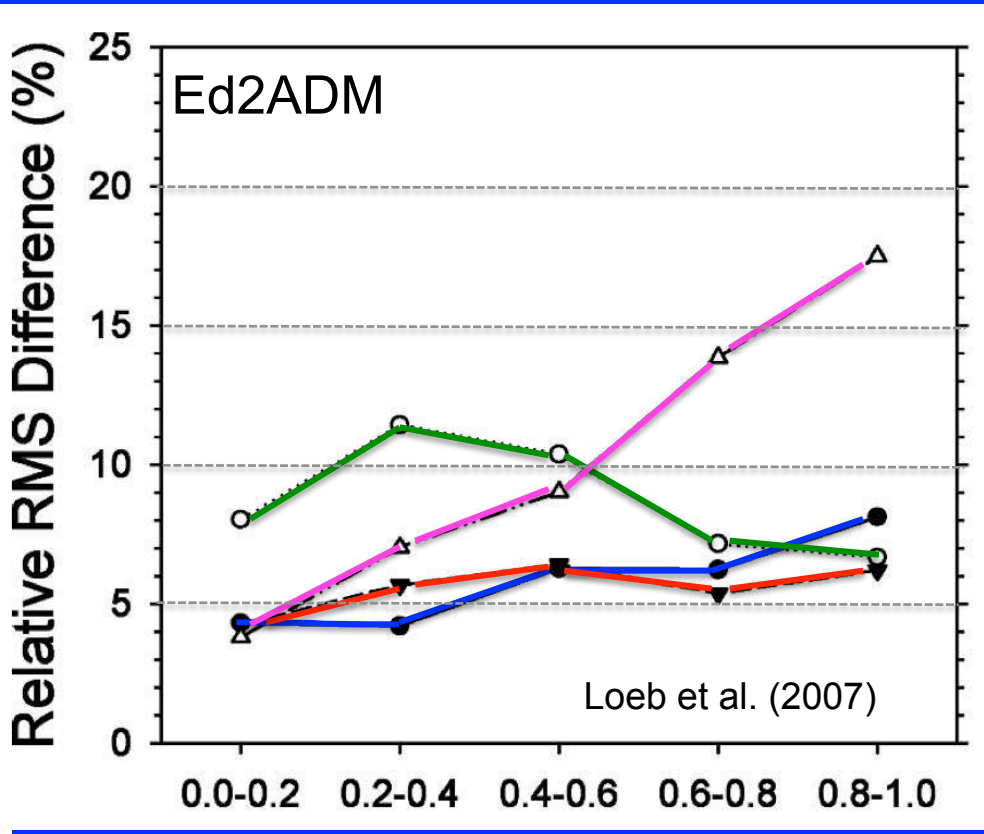
$$I_{sw}^{md} = d_0 + d_1 I_{0.65} + d_2 I_{0.86} + d_3 I_{1.63}$$

- Apply CERES ADM to nadir-viewing MODIS "broadband" radiance and to oblique-viewing (θ=50°-60°) CERES broadband radiance
- Calculate the relative RMS difference between nadir-viewing and oblique-viewing fluxes

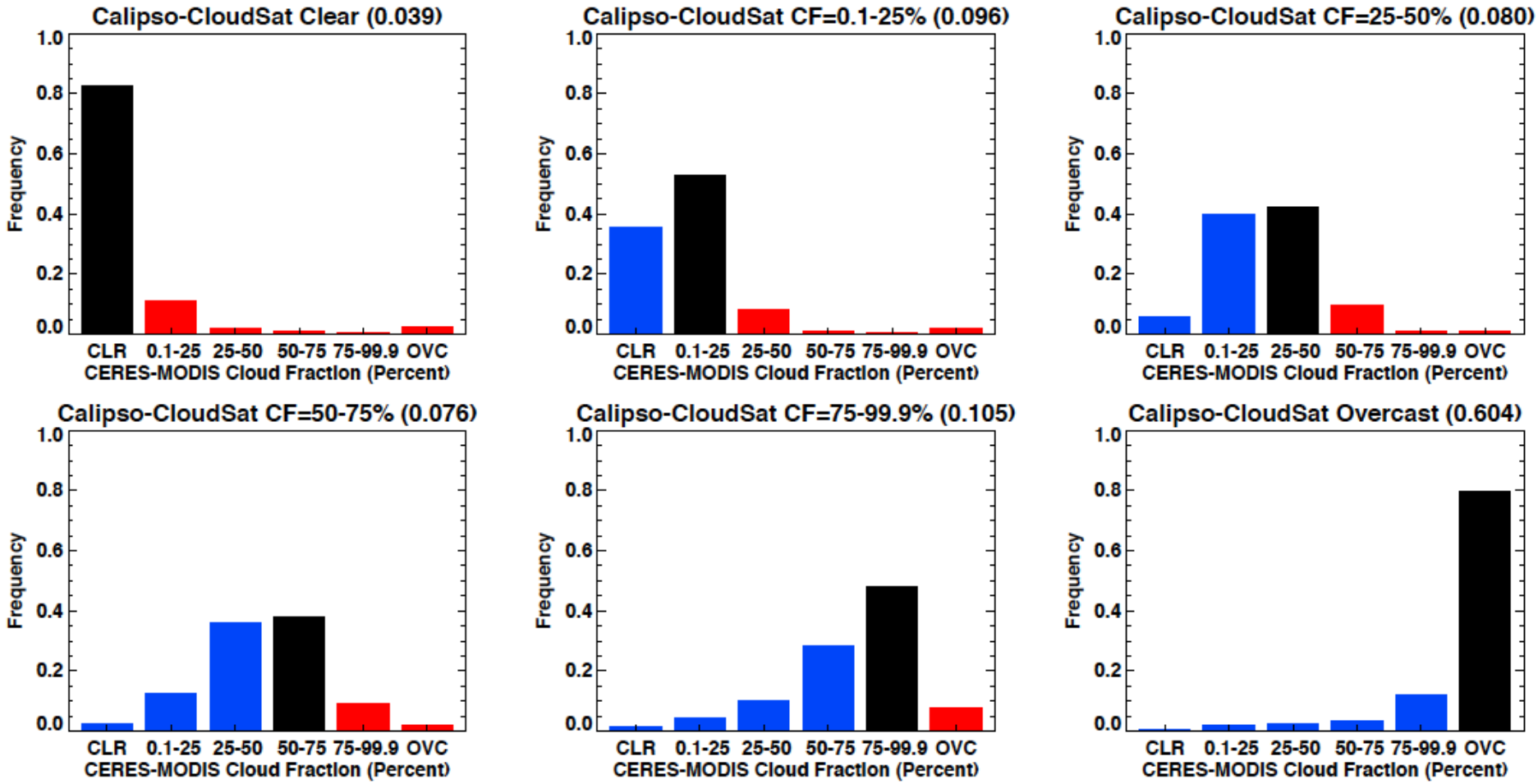
$$\psi = \frac{\sqrt{\frac{1}{N}\sum_{i=1}^{N}\left[F(\theta_i^n) - F(\theta_i^o)\right]^2}}{\frac{1}{N}\sum_{i=1}^{N} F(\theta_i^o)} \times 100\%$$

CERES-MODIS flux consistency over clear ocean: dependence on MODIS fine mode fraction is smaller than using Ed2ADM

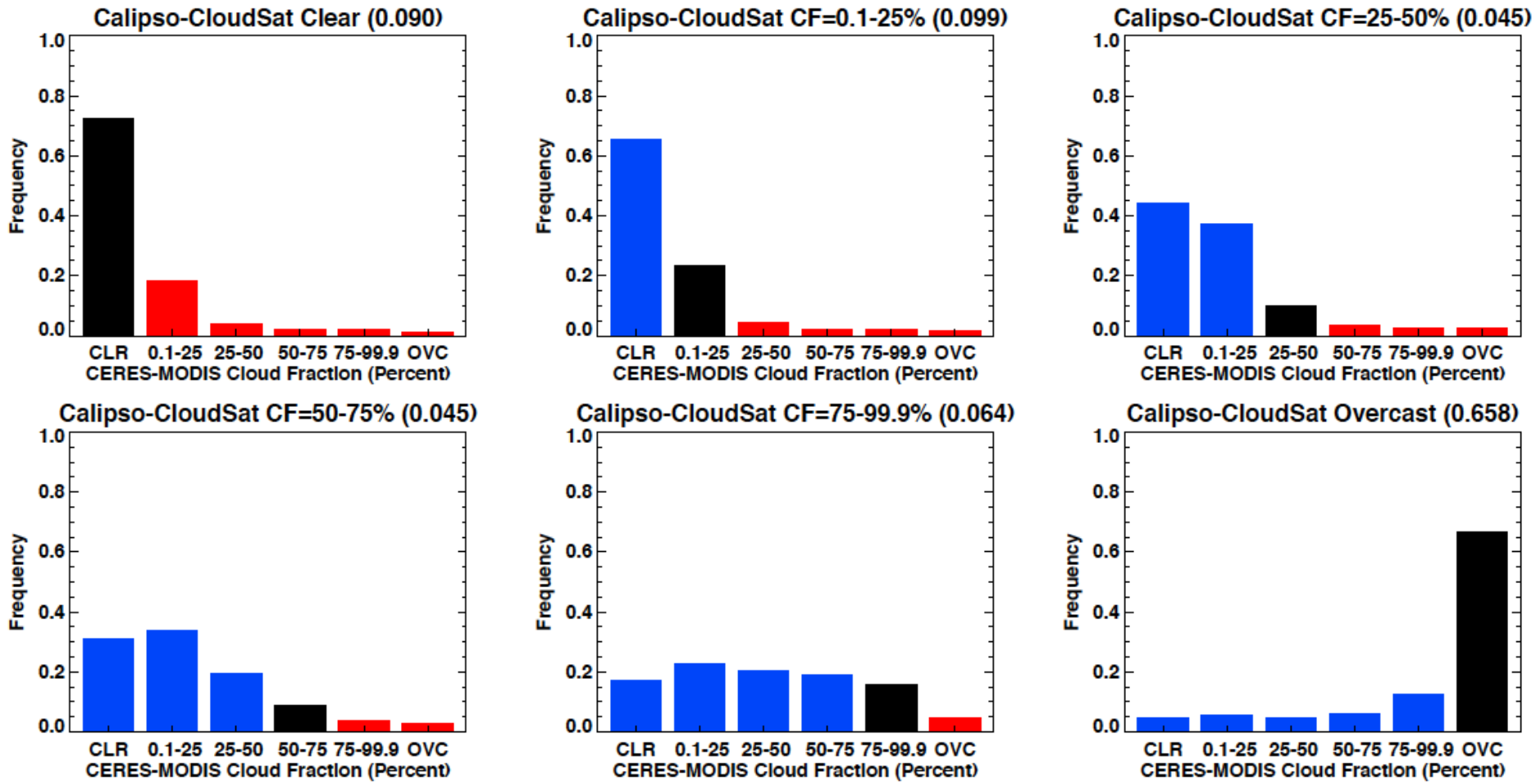




Cloud fraction difference between Ed4 cloud mask and Calipso-Cloudsat: Ocean daytime



Cloud fraction difference between Ed4 cloud mask and Calipso-Cloudsat: Land nighttime



More talks on ADM

- Zach Eitzen: Edition 4 longwave angular distribution models
- Joe Corbett: Use MODIS spectral information for CERES fresh snow angular distribution models
- Yong Hu: CALIPSO/MODIS comparisons of multi-layer clouds, and potential impact on radiation budget estimates

Summary

- Ed4 cloud algorithm produces higher cloud fraction and thinner clouds than Ed2 cloud algorithm
- Compare to Ed3, Ed4 global annual mean instantaneous SW flux increases by 0.8~1.0 Wm-2, daytime LW flux increases by 0.2~0.4 Wm-2, and nighttime LW flux is about the same
- Direct integration of SW indicates that zonal mean flux error is generally less than 0.5 Wm-2, and global mean flux error is less than 0.2 Wm-2
- Direct integration of LW indicates that zonal mean flux error is generally less than 0.5 Wm-2, and global mean flux error is less than 0.4 Wm-2
- CERES-MISR consistency test shows that the overall relative consistency of all-sky TOA fluxes is between 5~6% (14~18 Wm-2).
- CERES-MODIS consistency test over clear ocean indicates that the dependence of flux error on MODIS aerosol optical depth and fine mode fraction is reduced.

Future plan

- Ed4 ADMs is almost complete
- Validation effort is underway
- Deliver Ed4ADM first week of Dec. 2013
- Summarize Ed4ADM algorithm/validation for publication

Surface elevation and surface roughness