TOA Radiative Flux Estimation From CERES/Terra Angular Distribution Models

Norman G. Loeb

Hampton University/NASA Langley Research Center

Hampton, VA

Contributors: S. Kato, K. Loukachine, N. M. Smith, D.A. Rutan

October 16, 2003

CERES Data Used in Terra ADM Development

- Terra ADMs based on 2 years of CERES/Terra measurements.
- CERES/TRMM used only to fill in angular bins at small solar zenith angles.
- Scene Identification based on CERES Edition1A cloud properties.
- Terra SSF Edition2 will use new cloud algorithm for nighttime polar and twilight conditions.
- Terra SSF Edition2 will improve how microwave-based snow and sea-ice fraction is represented over a CERES FOV.
- Terra SSF Edition2 will use GEOS 4 instead of ECMWF

NAMING CONVENTIONS:

i) ADMs

ED1 = ED2B CERES/TRMM ADMs applied to CERES/Terra

ED2 = Developed from 2yr CERES/Terra with ED1 cloud algorithm

ii) Cloud Algorithm

ED1 = Run on 2yr of MODIS (has bugs in polar night and twilight conditions)

ED2 = Fixes polar night and twilight bugs in ED1

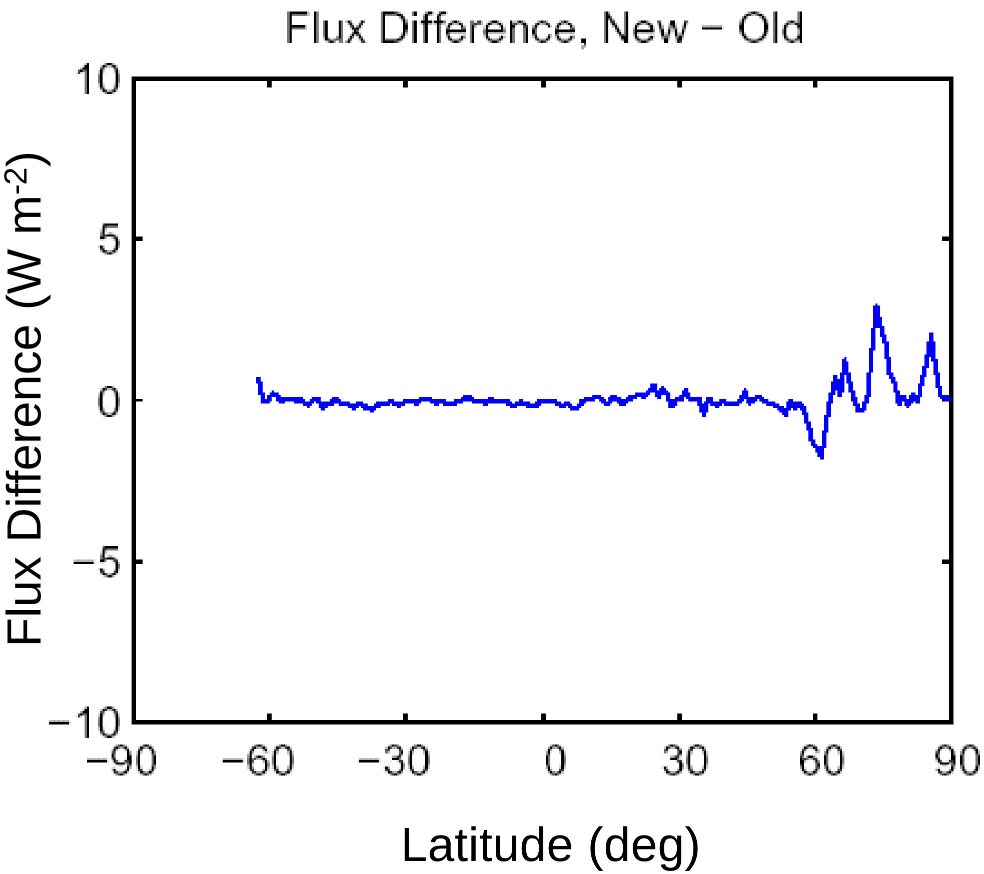
iii) SSF Product

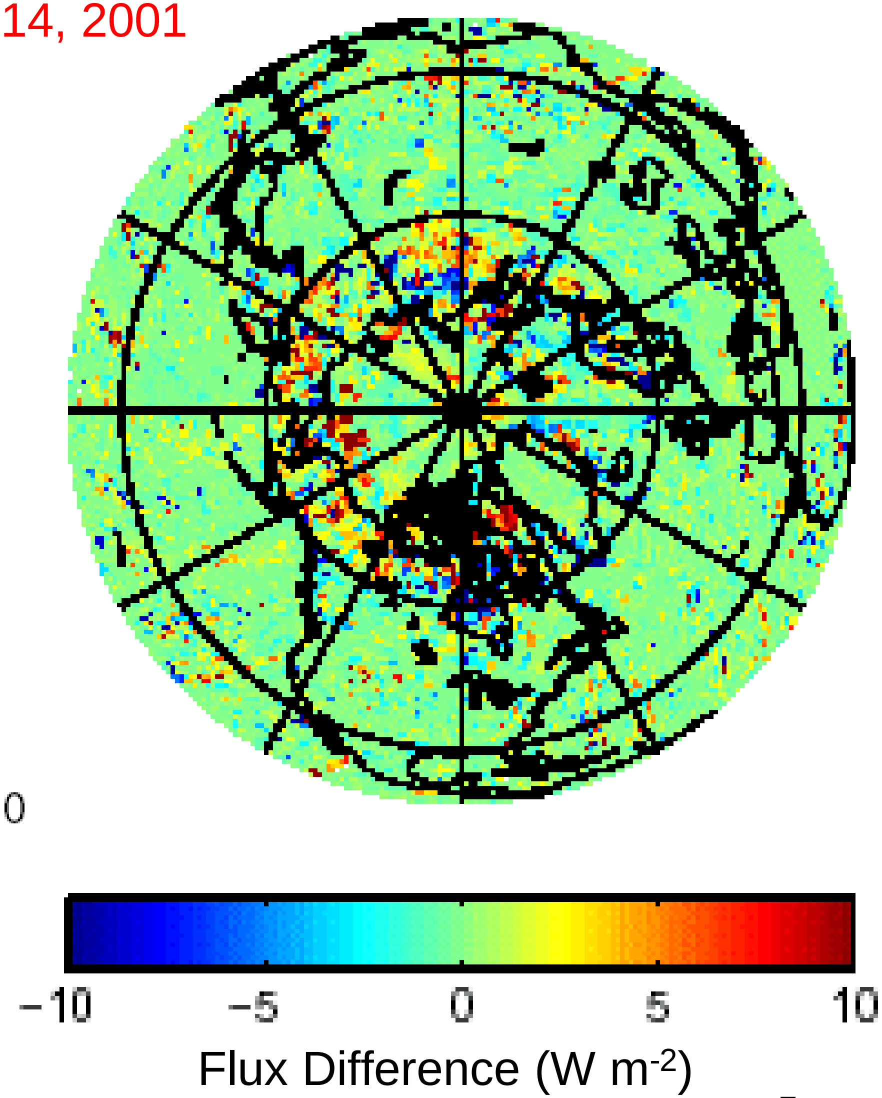
SSF	Clouds	TOA Fluxes	Availability	Output
ED1A	ED1	Based on ED1 ADMs (CERES/TRMM ED2B)	2 years +	ED2 ADMs
ED2A	ED2	Based on ED2 ADMs developed using 2 years of **ED1** cloud algorithm	Proposed	Lots of Good Science?

Given that the new Terra ED2 ADMs were developed using the **ED1** cloud algorithm for scene identification, how do TOA fluxes change when the ED2 ADMs are applied using the improved **ED2** cloud algorithm?

Effect of Cloud Algorithm Changes on **SW** TOA Fluxes
F(ED2 Clouds) – F(ED1 Clouds) using new Terra ED2 ADMs

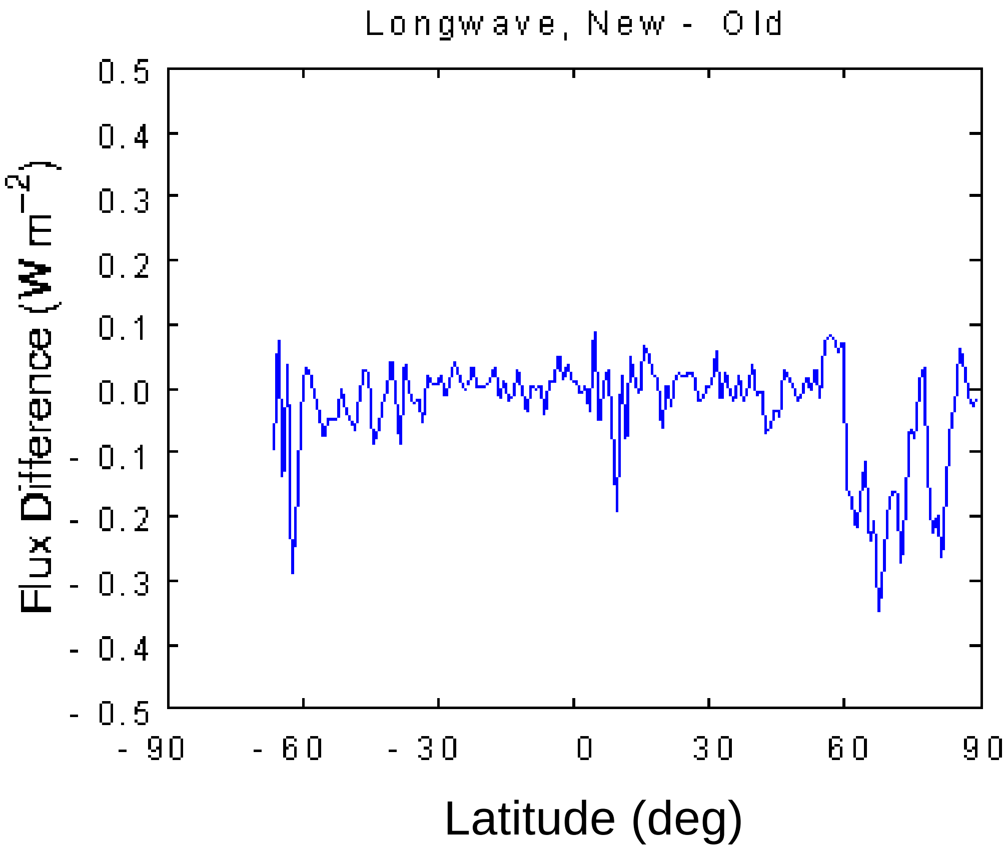
JUNE 14, 2001

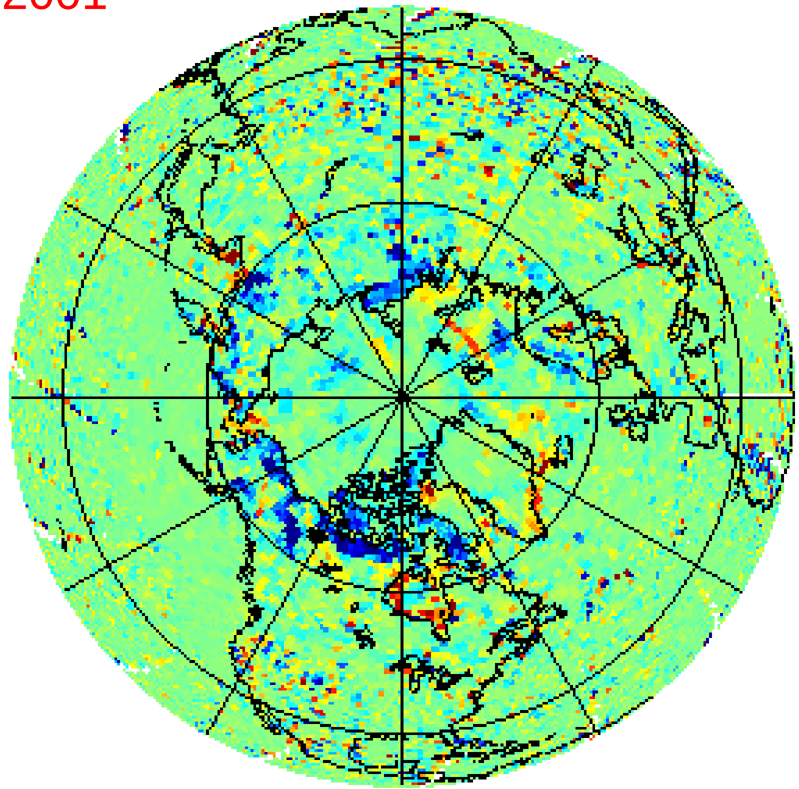


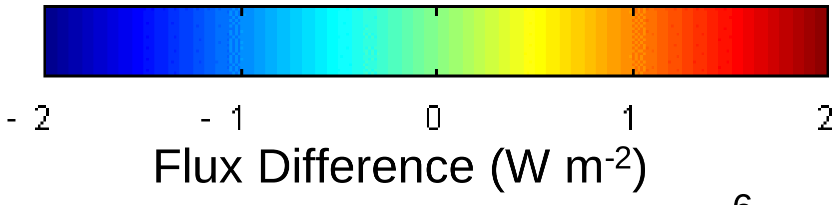


Effect of Cloud Algorithm Changes on **LW** TOA Fluxes
F(ED2 Clouds) – F(ED1 Clouds) using new Terra ED2 ADMs

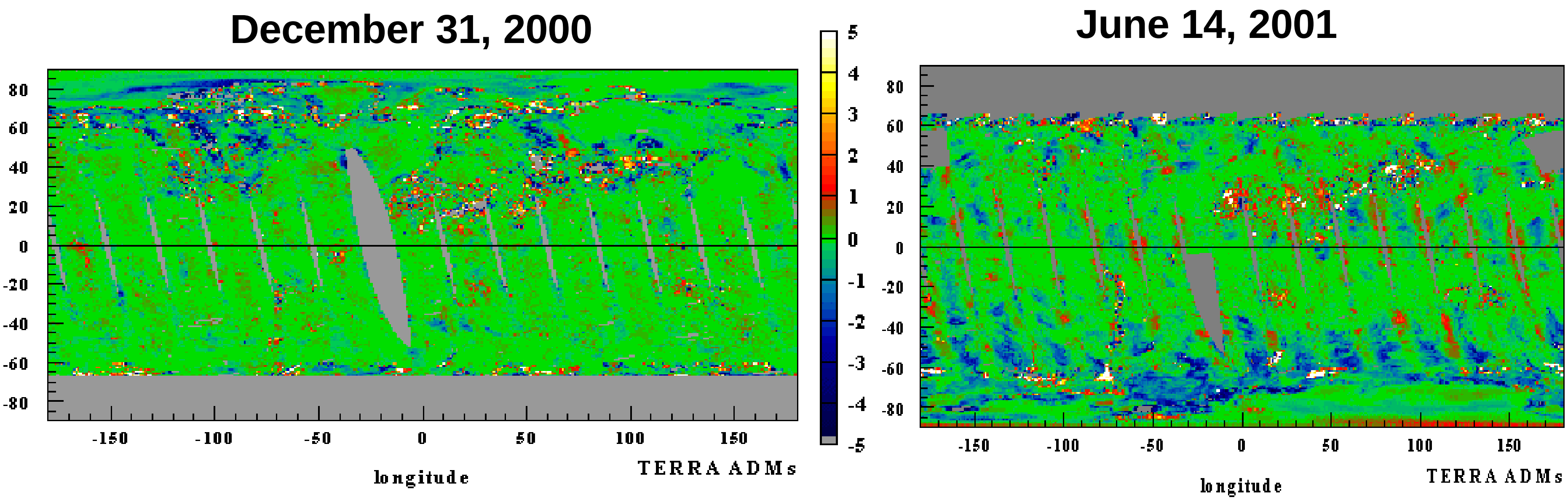
JUNE 14, 2001

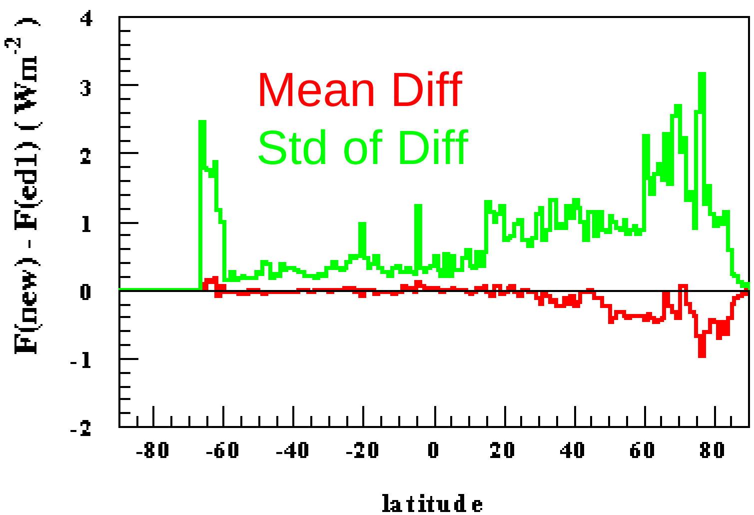


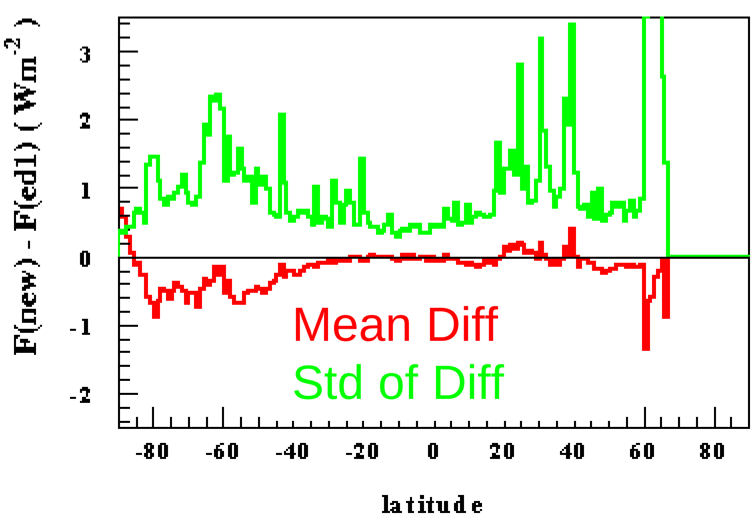




Effect of Cloud Algorithm Changes on **Nighttime LW** TOA Fluxes F(ED2 Clouds) – F(ED1 Clouds) using new Terra ED2 ADMs



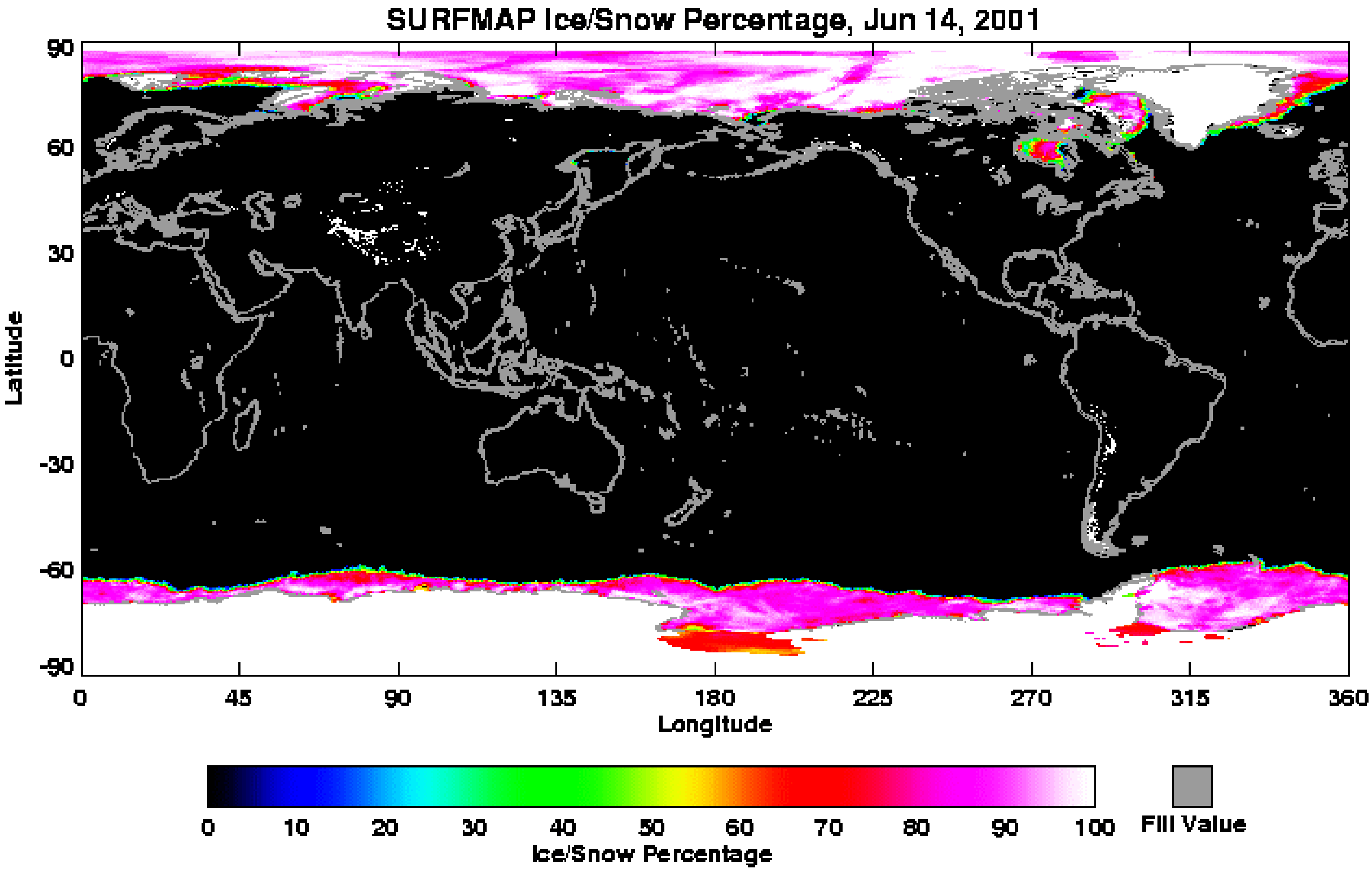




Snow & Sea-Ice Coverage on SSF

Snow info on SSF is inferred using snow and sea-ice map from NSIDC (based on SSM/I).

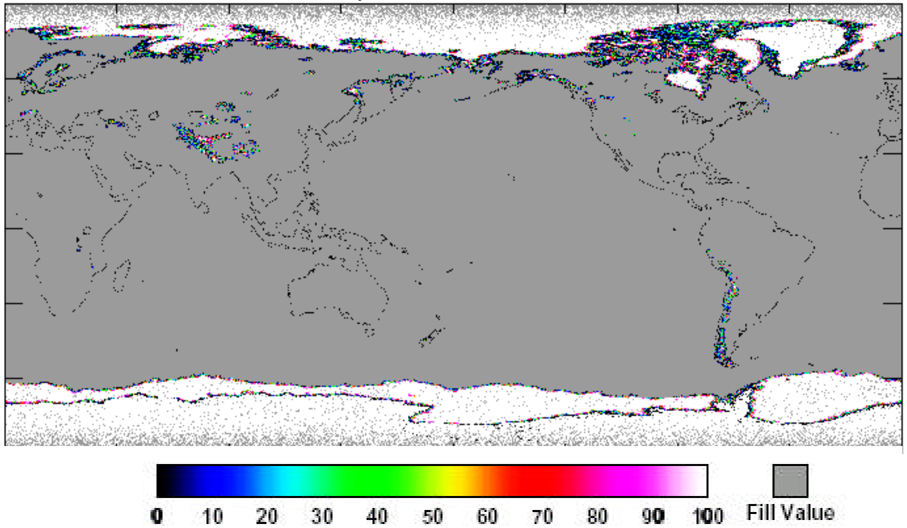
=>Fractional snow/sea-ice coverage is projected onto a 10' grid.



SSF ED1A used the NSIDC map incorrectly:

- **It assumed that if snow/sea-ice was present, it covered 100% of the area.**
- **ED2 snow & sea-ice ADMs were based on 2-years of this data.**

ED1 SSF (June 14, 2001)

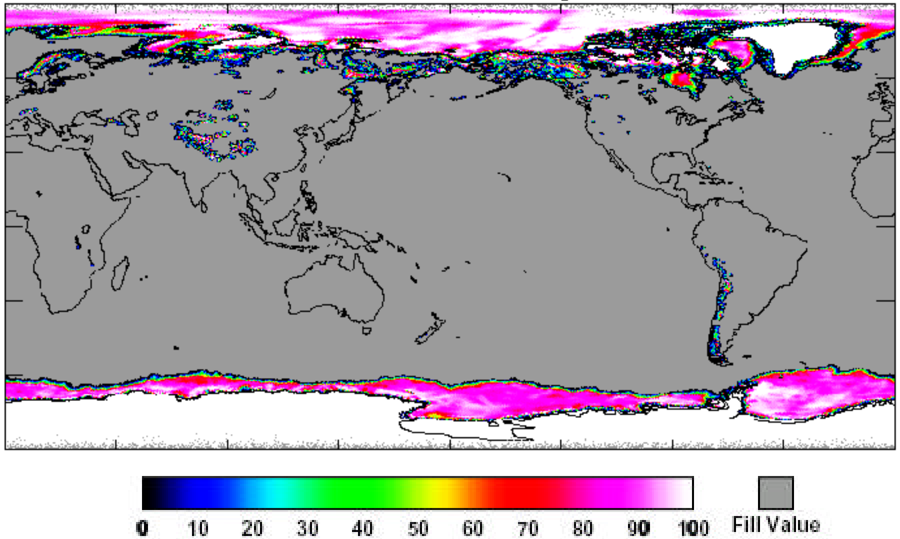


Ice/Snow Percentage Over Footprint

SSF ED2A will correct this problem:

ED2A will account for fractional sea-ice.

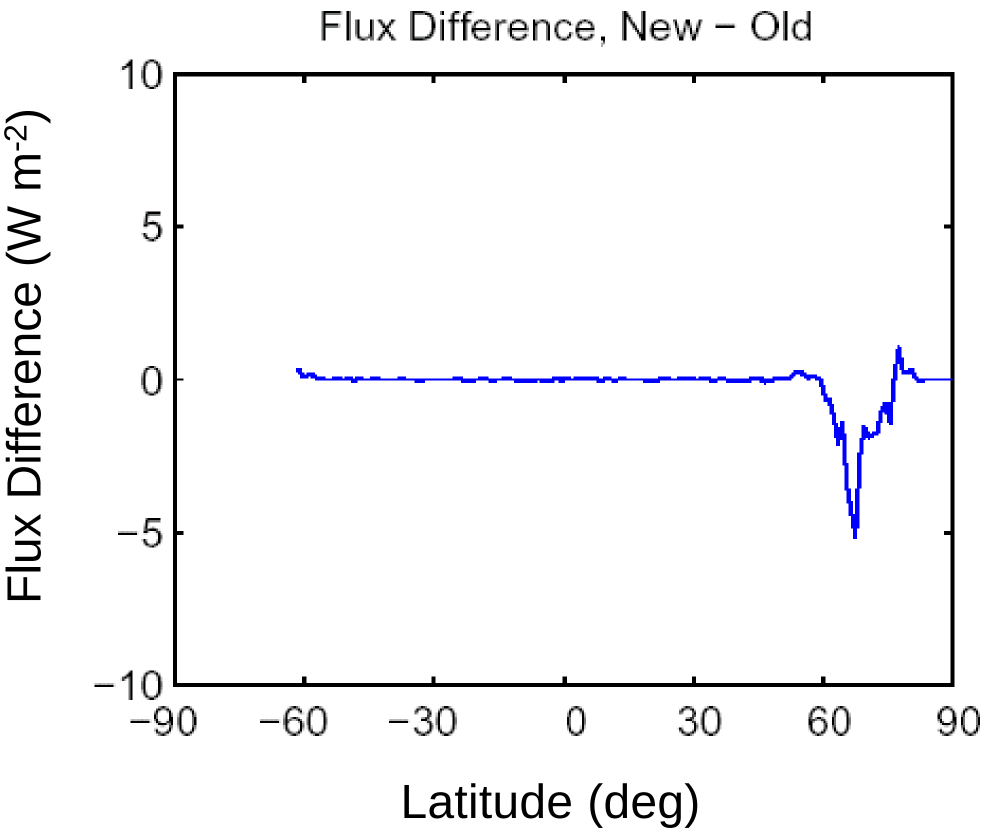
ED2 SSF (June 14, 2001)

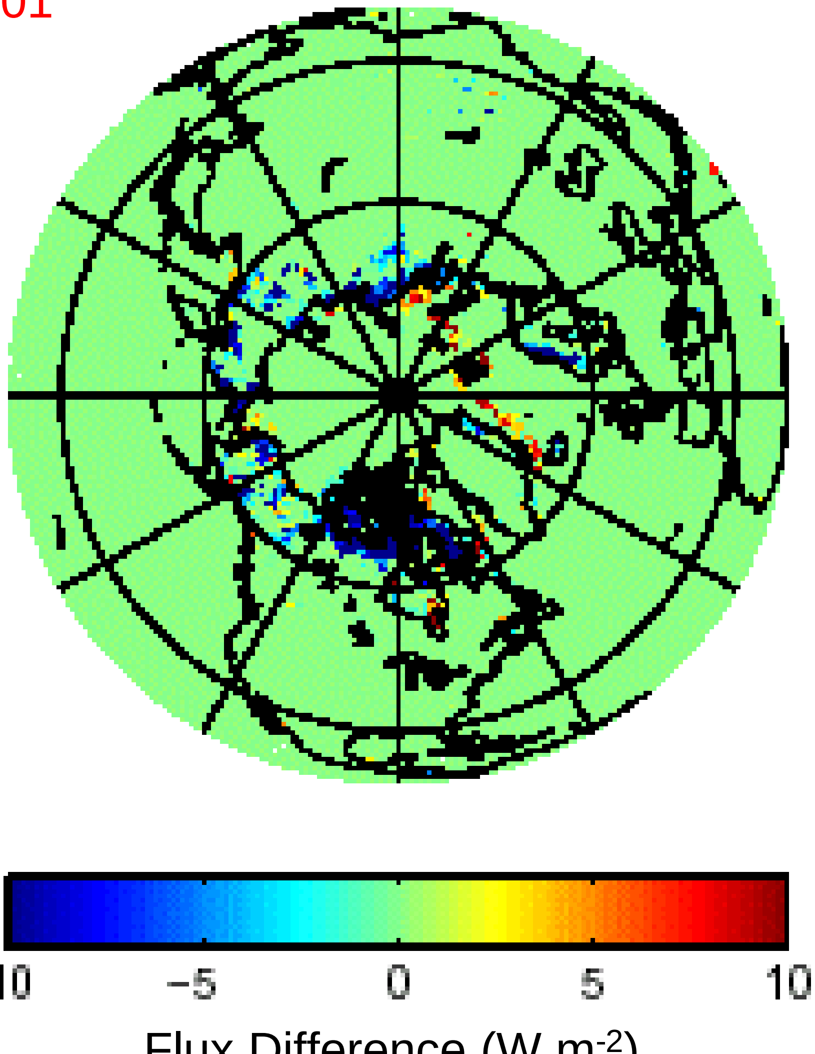


Ice/Snow Percentage Over Footprint

SW TOA Flux Sensitivity to Changes in SSF ED1A and ED2A Snow/Sea-Ice Fraction

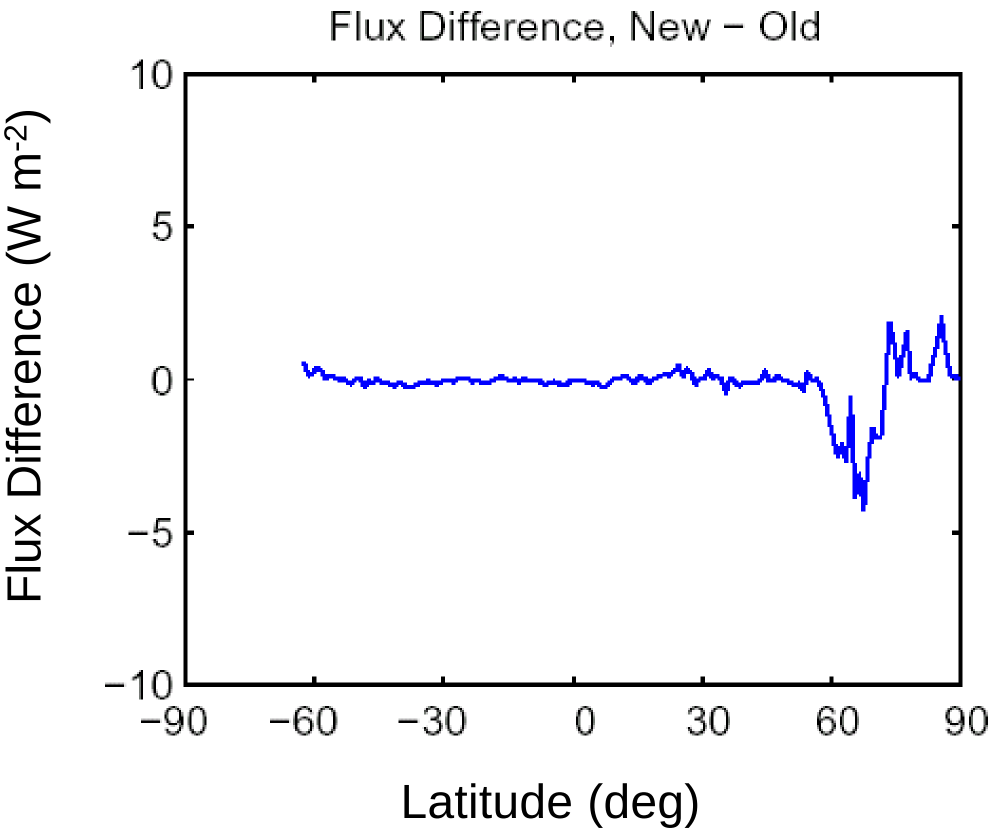
JUNE 14, 2001

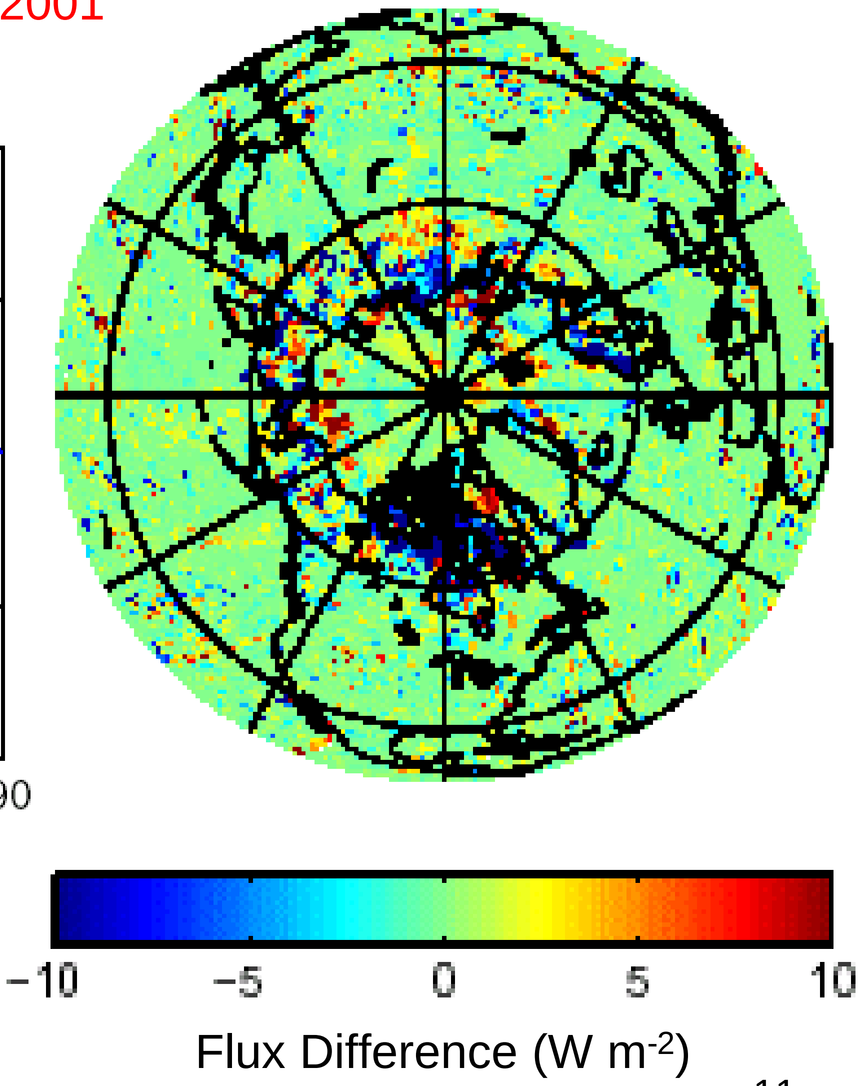




SW TOA Flux Sensitivity to Changes in **BOTH** Cloud Algorithm and Snow/Sea-Ice Fraction

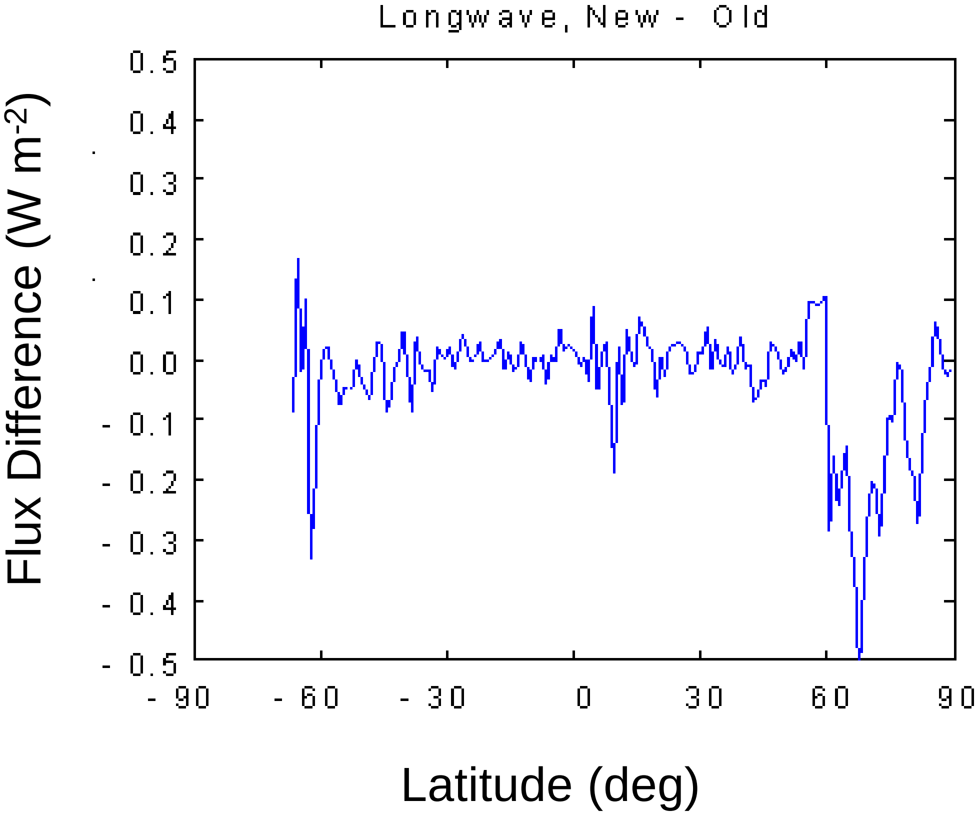
JUNE 14, 2001

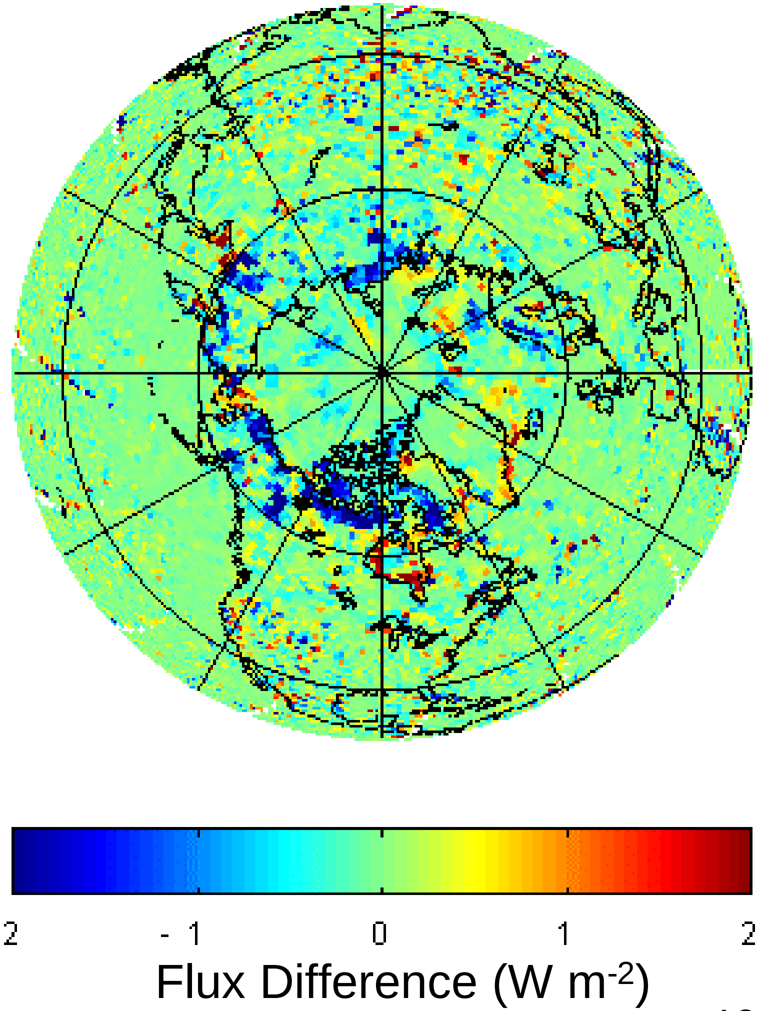




LW TOA Flux Sensitivity to Changes in **BOTH** Cloud Algorithm and Snow/Sea-Ice Fraction

JUNE 14, 2001





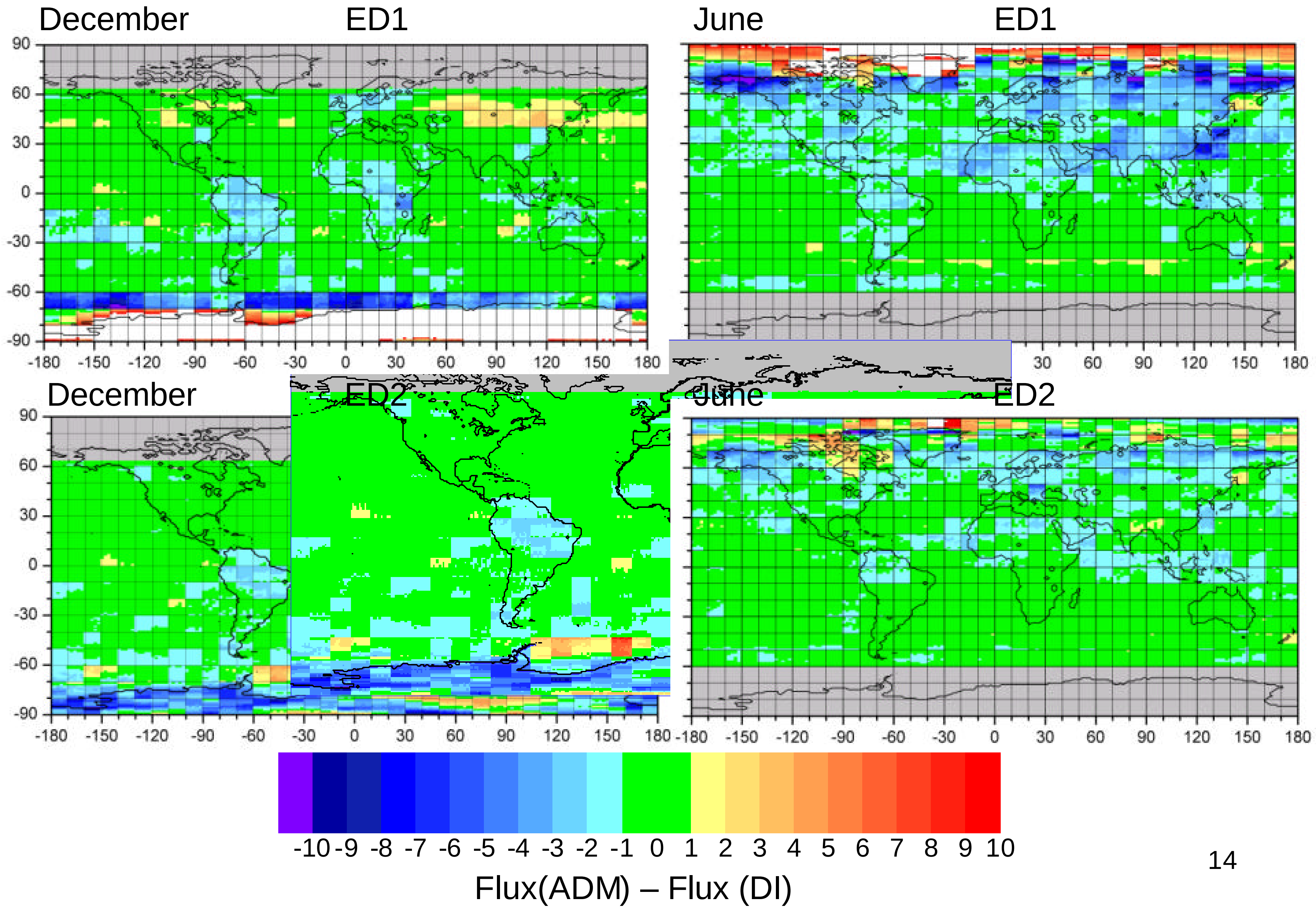
SW TOA Flux Validation

1) Direct Integration Test

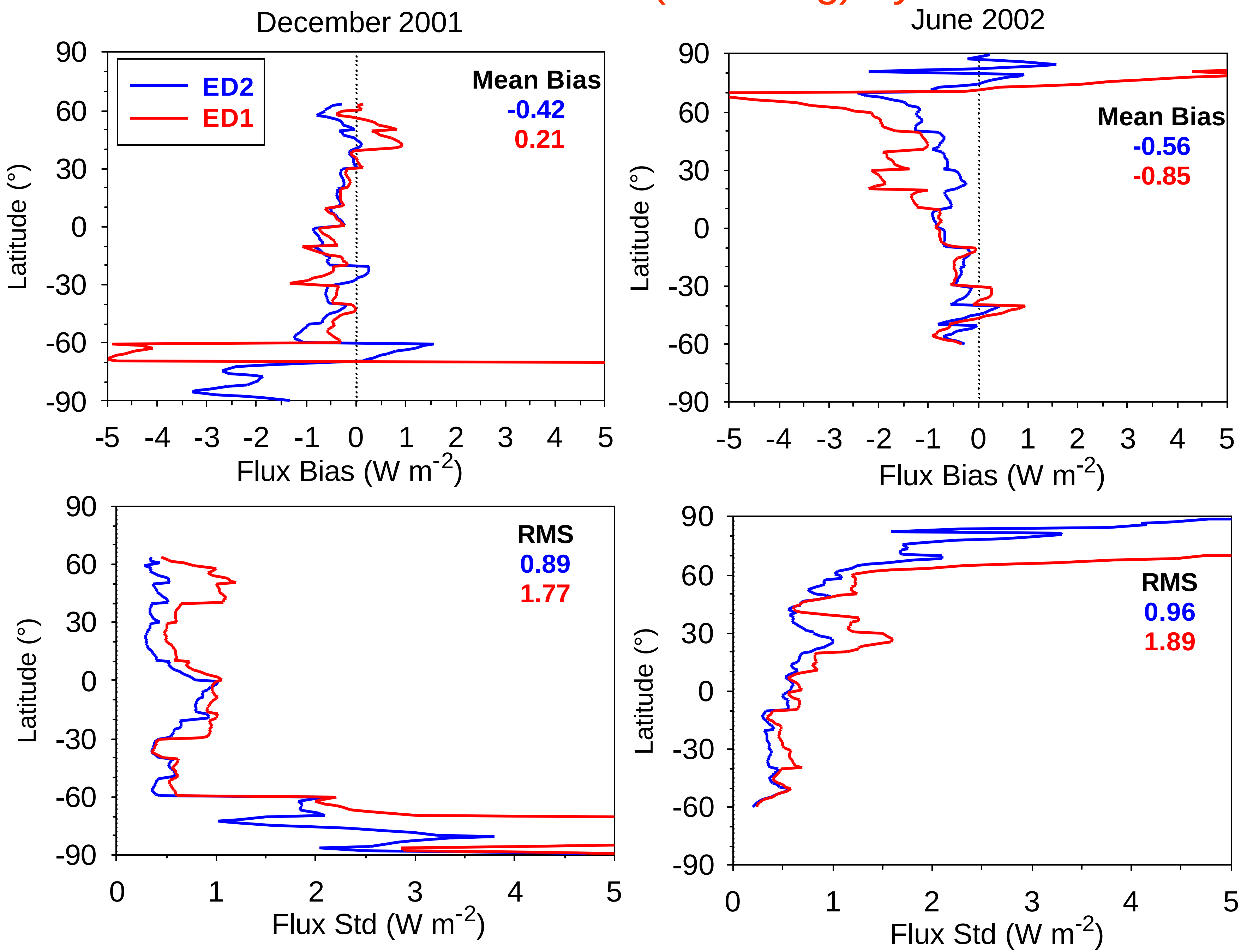
2) TOA flux differences between CERES/Terra ES8, ED1 and ED2

3) Alongtrack Consistency Tests

SW Flux Direct Integration Test



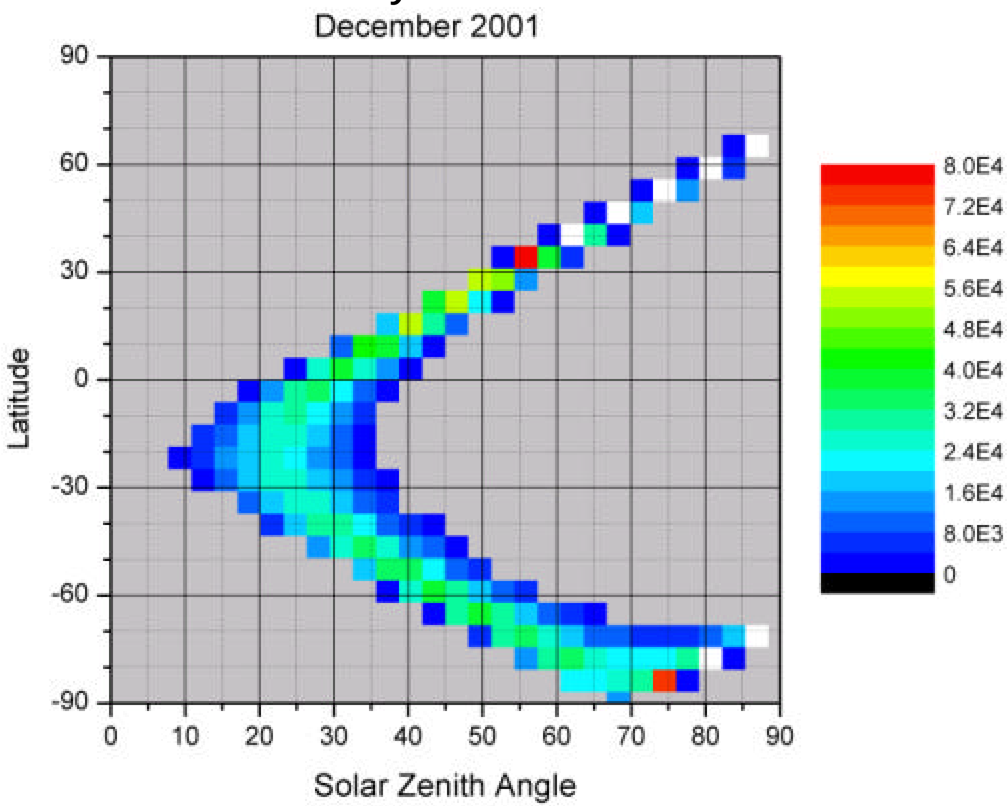
SW TOA Flux Errors (24-h avg) by Latitude



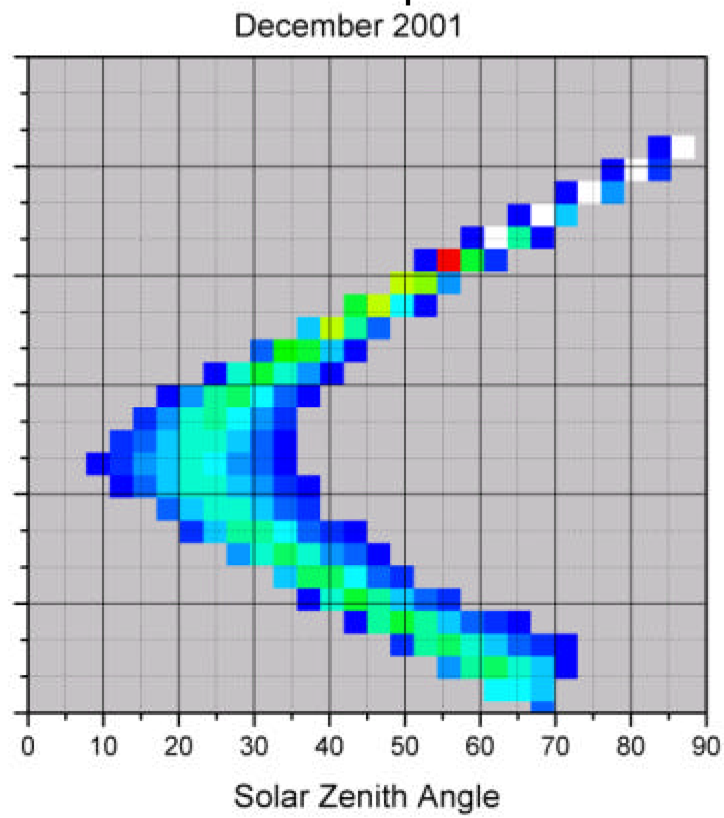
TOA Flux Differences Between CERES/Terra ES8, ED1 and ED2

- Compare ES8, ED1 and ED2 monthly mean from instantaneous clear and all-sky TOA fluxes (no diurnal averaging) for December 2001 and June 2002 crosstrack data.
- Use only daytime measurements at local times between 6 a.m. and 6 p.m.

All Daytime Hours



6 a.m. – 6 p.m.

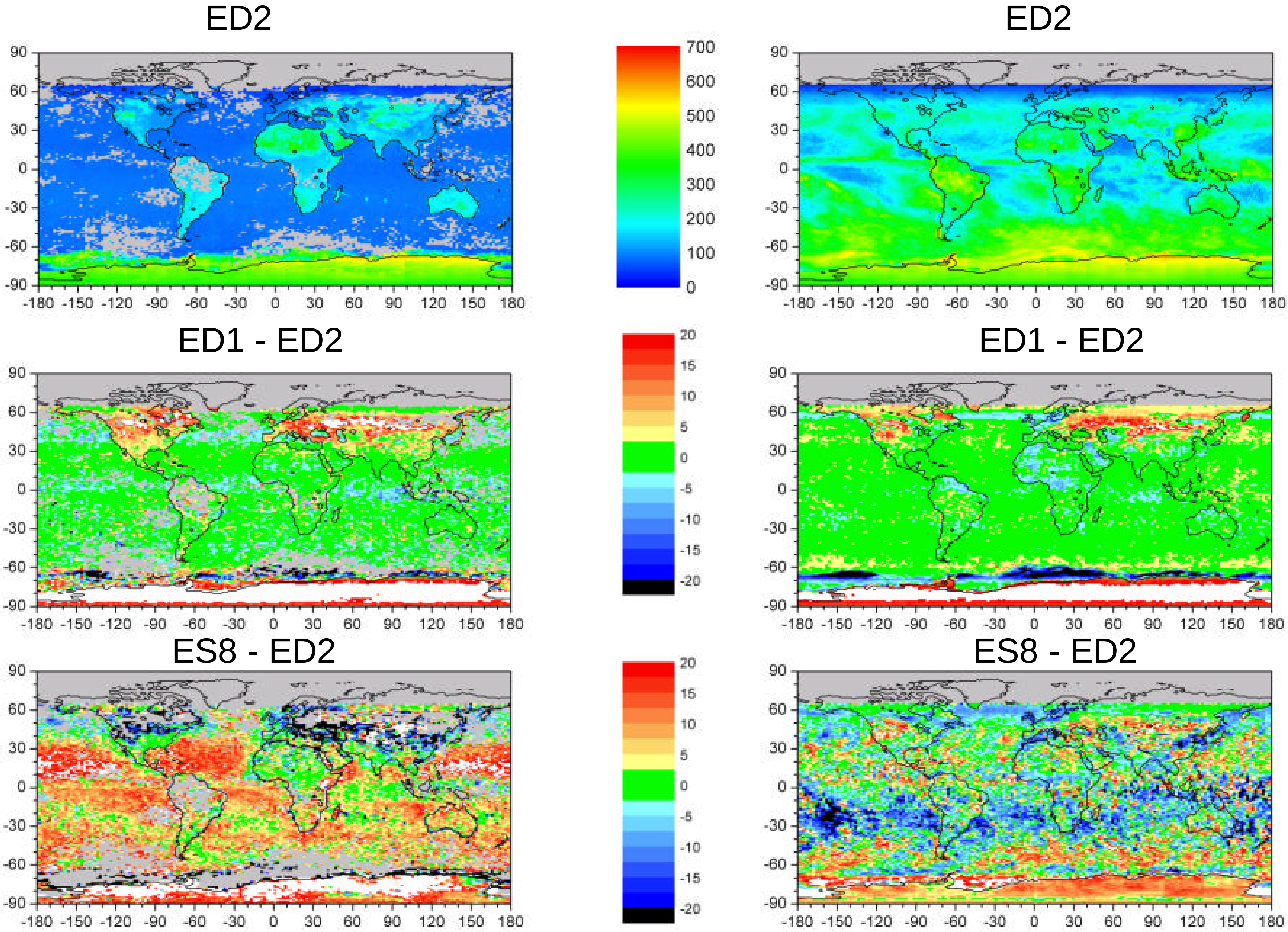


SW TOA Flux Comparisons

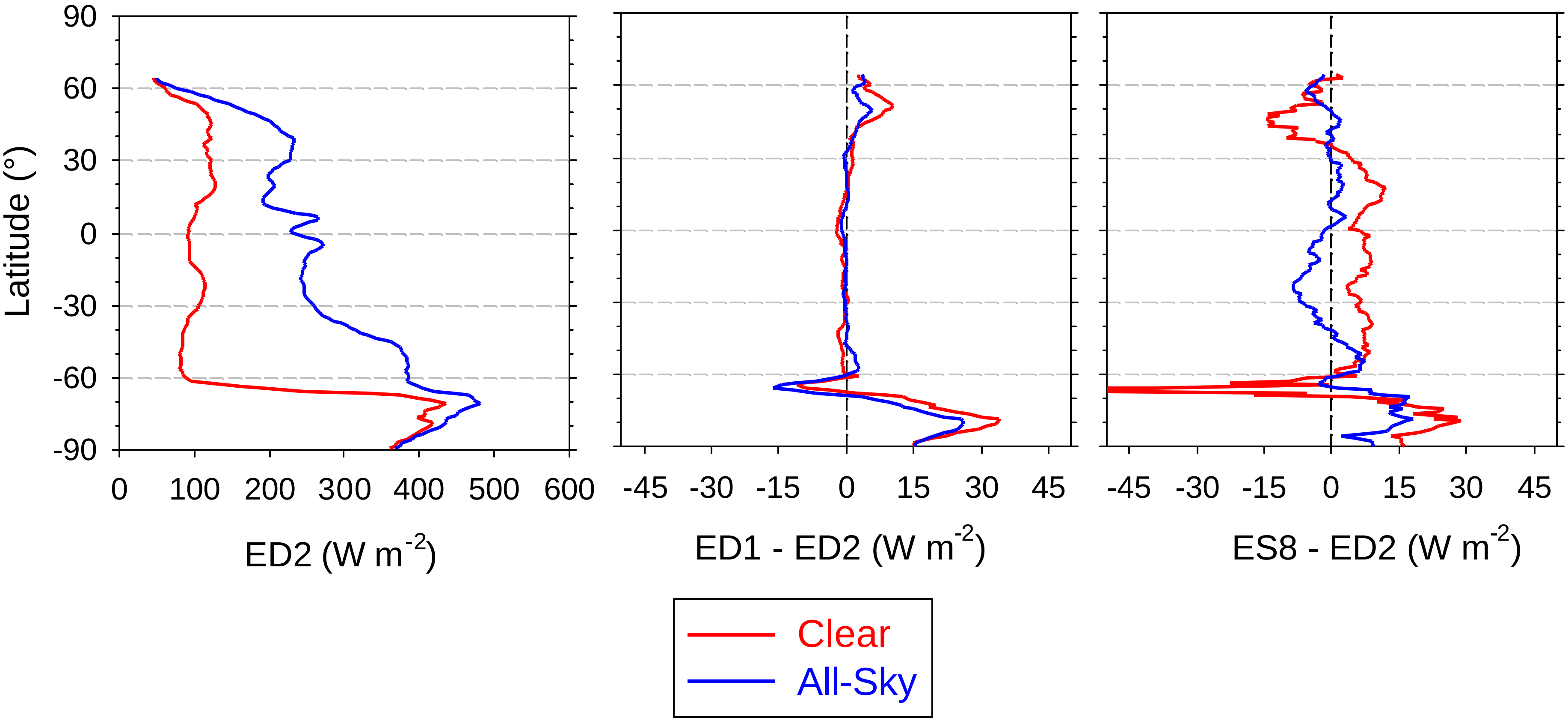
DECEMBER, 2001

CLEAR-SKY

All-SKY

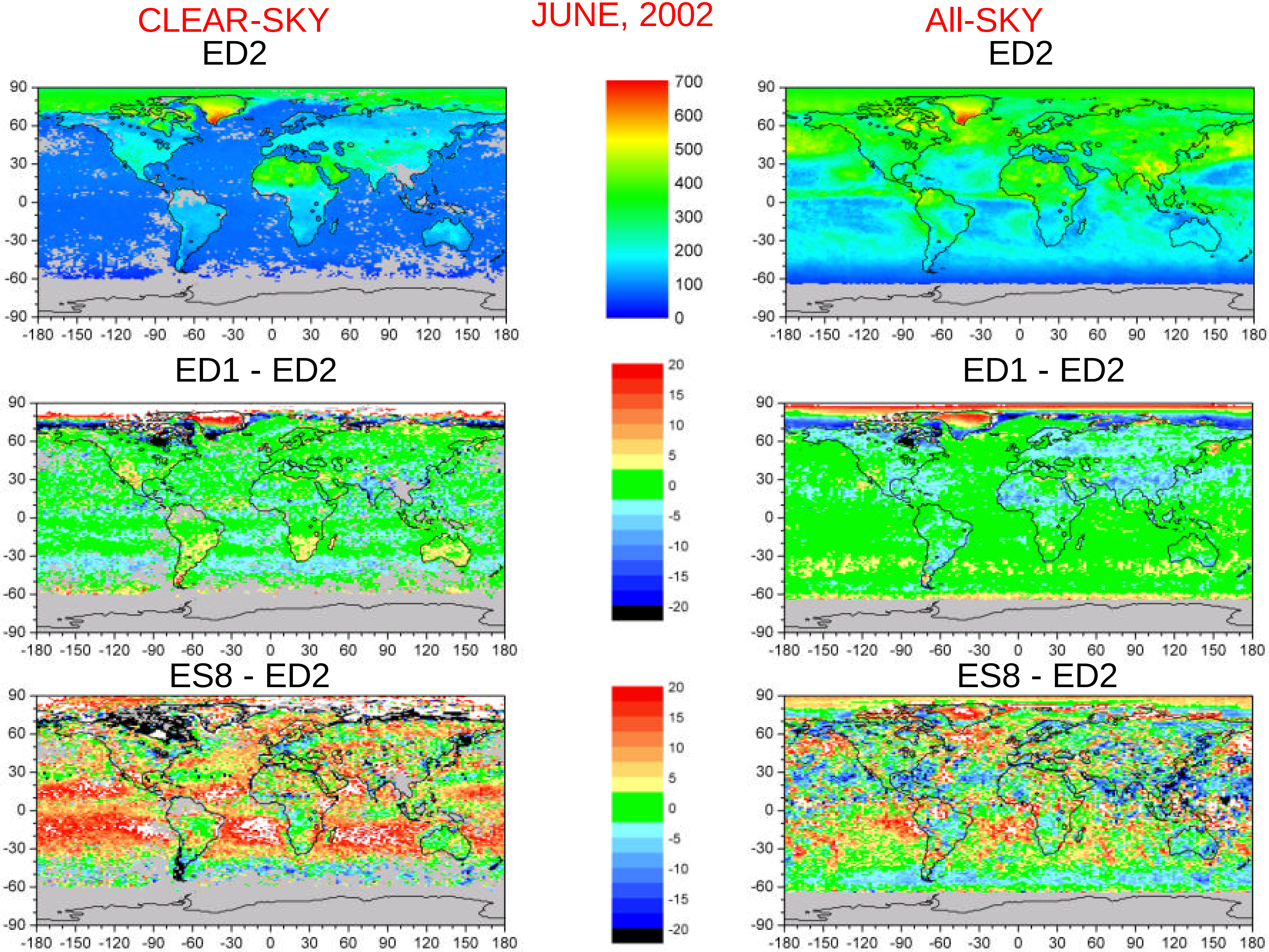


SW TOA Flux Comparison (December 2001)

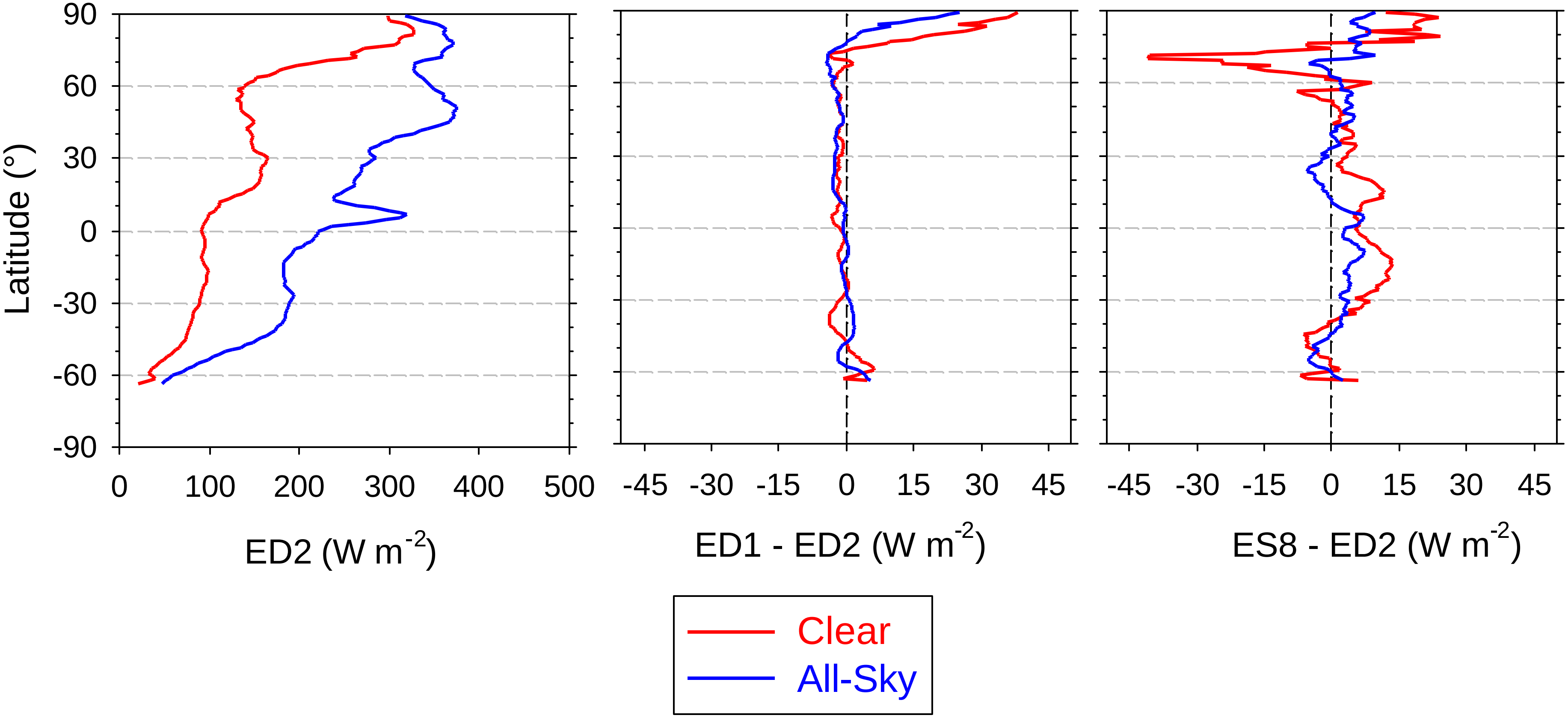


SW TOA Flux Comparisons

JUNE, 2002



SW TOA Flux Comparison (June 2002)



SW TOA Flux Differences: ES8 & ED1 vs ED2 (December 2001)

	Avg	Avg Diff		RMS Diff		
				1°-Regional		FOV
	ED2	ES8 vs ED2	ED1 vs ED2	ES8 vs ED2	ED1 vs ED2	ED1 vs ED2
Clear (30°S-30°N)	107.1	7.2	-0.6	12.1	3.3	5.0
All-Sky (30°S-30°N)	233.9	-2.0	-0.3	9.2	1.9	10.8
Clear (Global)	117.4	3.8	1.1	22.3	6.0	7.0
All-Sky (Global)	255.4	-0.6	0.7	9.0	3.9	11.9

Notes: i) Diff = SW Flux(ES8) – SW Flux(ED2) or SW Flux(ED1) – SW Flux(ED2)

ii) No diurnal Averaging

iii) All fluxes in W m^{-2}

iv) 30°S-30°N insolation = 1121 W m^{-2}; Global = 956 W m^{-2}

SW TOA Flux Differences: ES8 & ED1 vs ED2 (June 2002)

	Avg	Avg Diff		RMS Diff		
				1°-Regional		FOV
	ED2	ES8 vs ED2	ED1 vs ED2	ES8 vs ED2	ED1 vs ED2	ED1 vs ED2
Clear (30°S-30°N)	111.4	8.3	-1.4	13.2	3.6	4.9
All-Sky (30°S-30°N)	230.5	2.1	-1.1	10.0	2.3	10.3
Clear (Global)	116.4	4.3	-0.9	21.5	6.0	6.1
All-Sky (Global)	239.5	1.6	-0.9	9.5	3.5	11.1

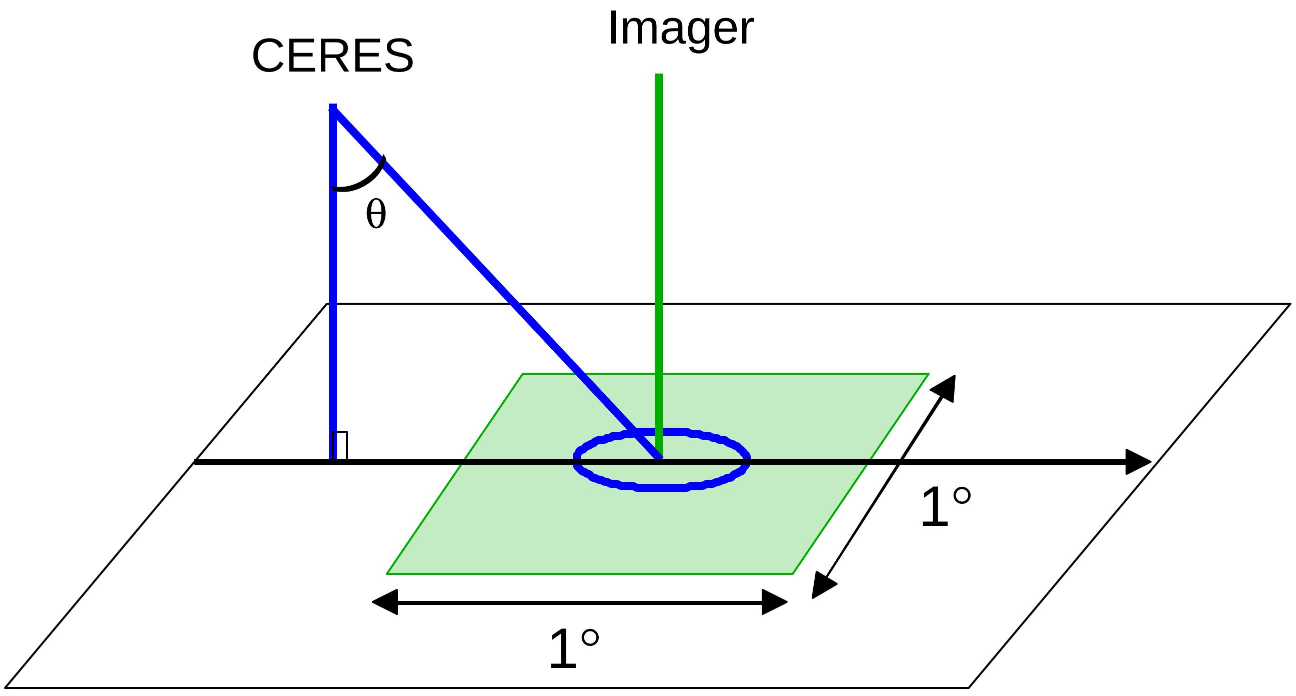
Notes: i) Diff = SW Flux(ES8) – SW Flux(ED2) or SW Flux(ED1) – SW Flux(ED2)

ii) No diurnal Averaging

iii) All fluxes in W m^{-2}

iv) 30°S-30°N insolation = 1107 W m^{-2}; Global = 954 W m^{-2}

Instantaneous TOA Flux Consistency Tests



- Convert imager nadir visible radiance to broadband flux
- Compare off-nadir CERES flux with nadir flux inferred from imager visible radiance
- 41 global alongtrack days over 2 years

Approach

- Convert imager nadir visible radiance to broadband flux:
  - i) Narrow-to-broadband radiance regression developed using instantaneous nadir CERES and imager radiances over 1° regions.
  - ii) Retain only cases where error in fit is < 3% (≈57% of popl'n)
  - iii) Apply CERES ADMs to CERES off-nadir and imager nadir broadband radiances.
- Compare off-nadir and nadir instantaneous TOA fluxes by latitude, region, IGBP type, cloud type, etc.

Regional Stratification:

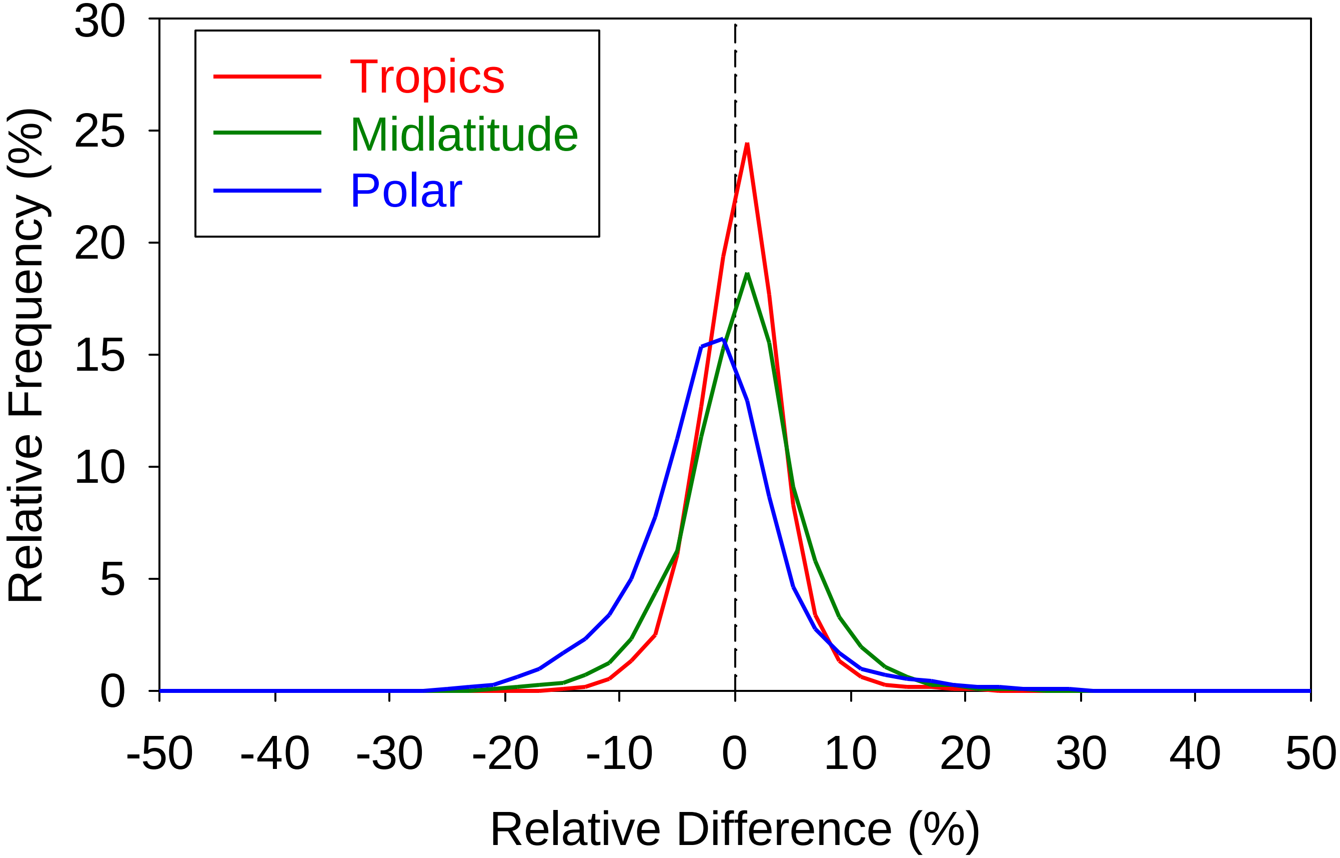
Tropics - Lat ≤ 30°, Ocean, Land, Desert

Midlatitudes - Lat > 30°, Ocean, Land, Desert

Polar - Global, FOV contains Snow or Sea Ice

Clear-Sky Instantaneous SW TOA Flux Consistency: **Terra ADMs**

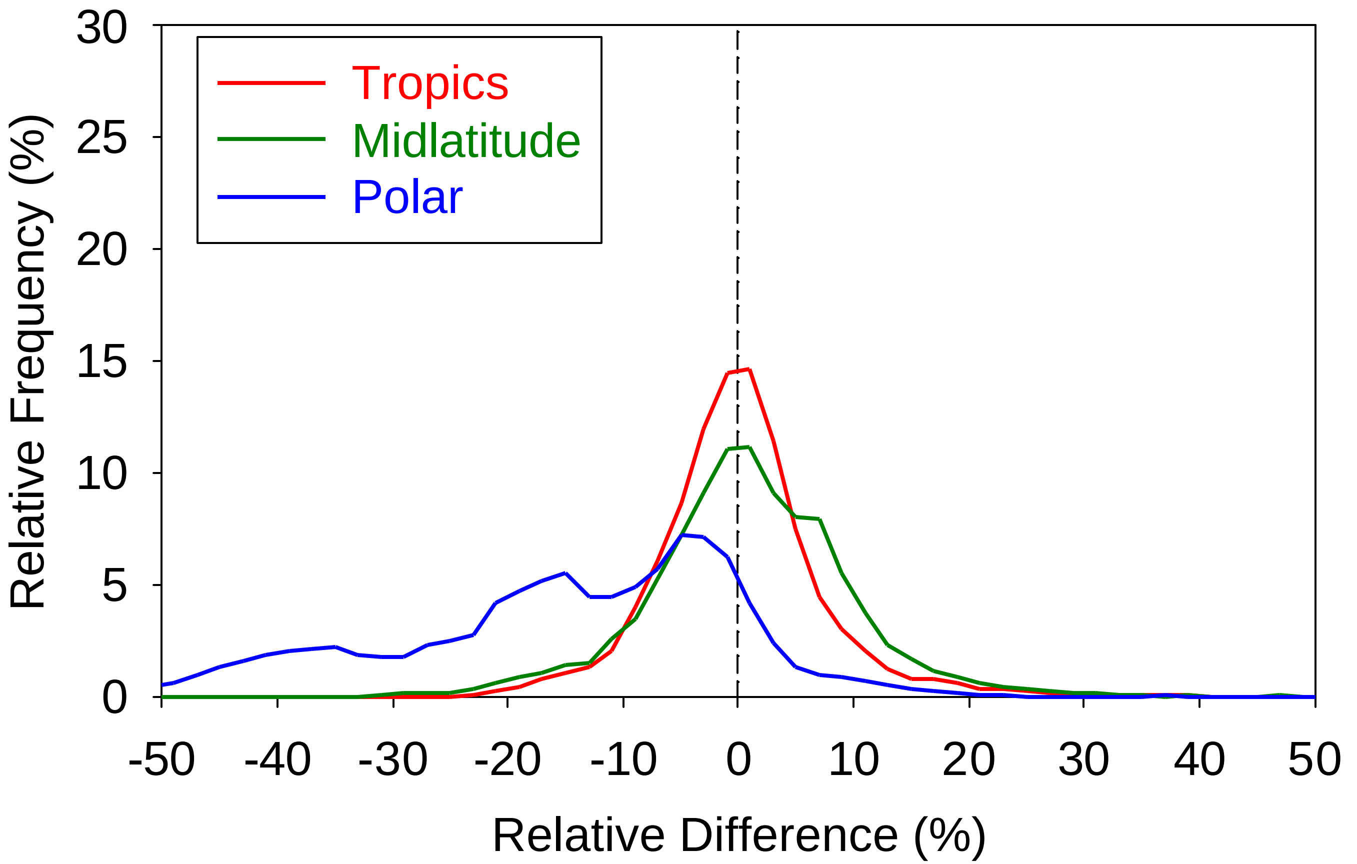
[F(q=50°-60°) - F(Nadir)] / F(Nadir) x 100%



Region	Mean SW Flux ($W m^{-2}$)	Bias (%)	RMS (%)	No. FOVs
Tropics	223.3	0.6	3.7	32,352
Midlat	163.1	0.5	4.9	15,117
Polar	293.0	-2.0	6.5	19,105

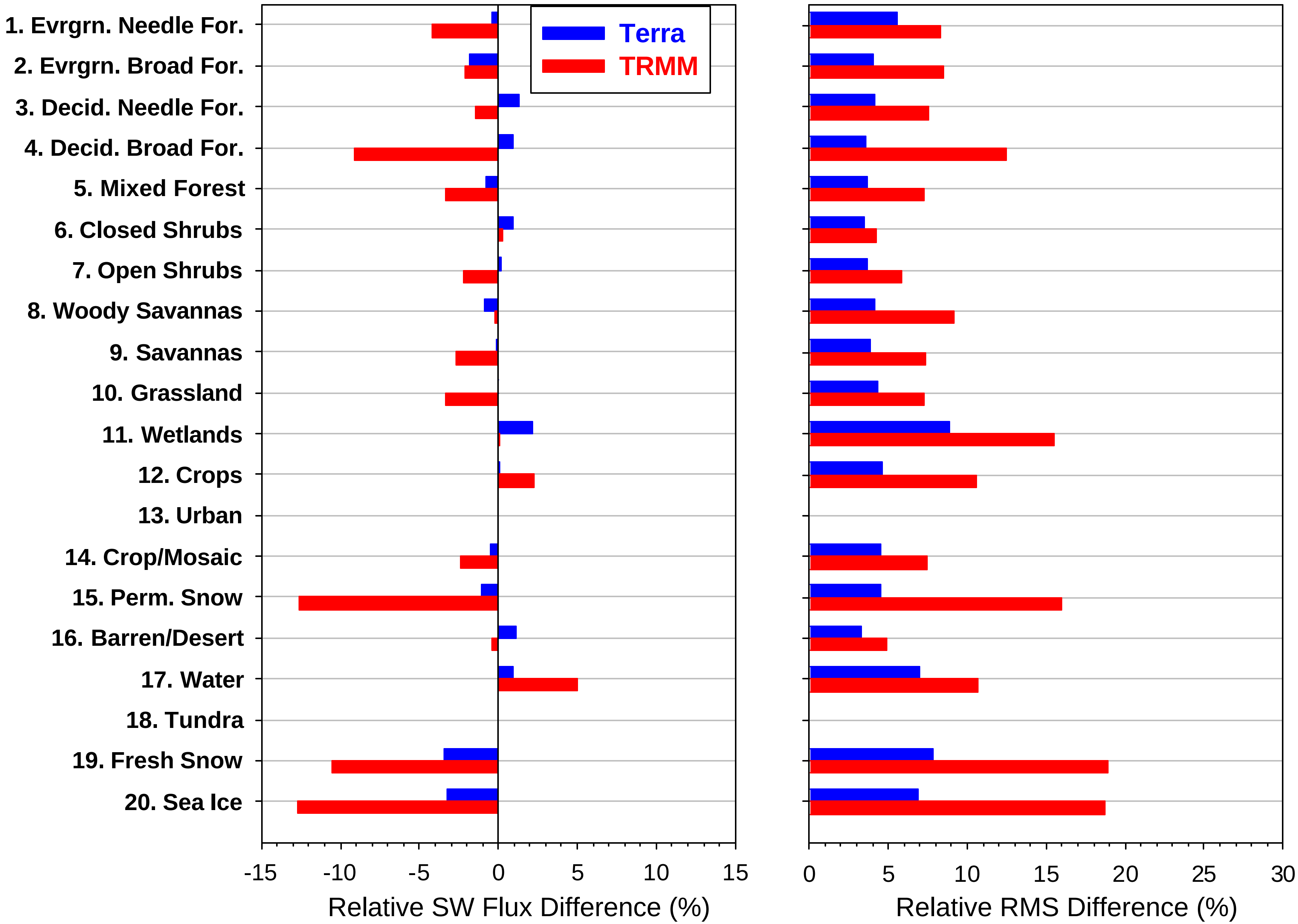
Clear-Sky Instantaneous SW TOA Flux Consistency: **TRMM ADMs**

[F(q=50°-60°) - F(Nadir)] / F(Nadir) x 100%



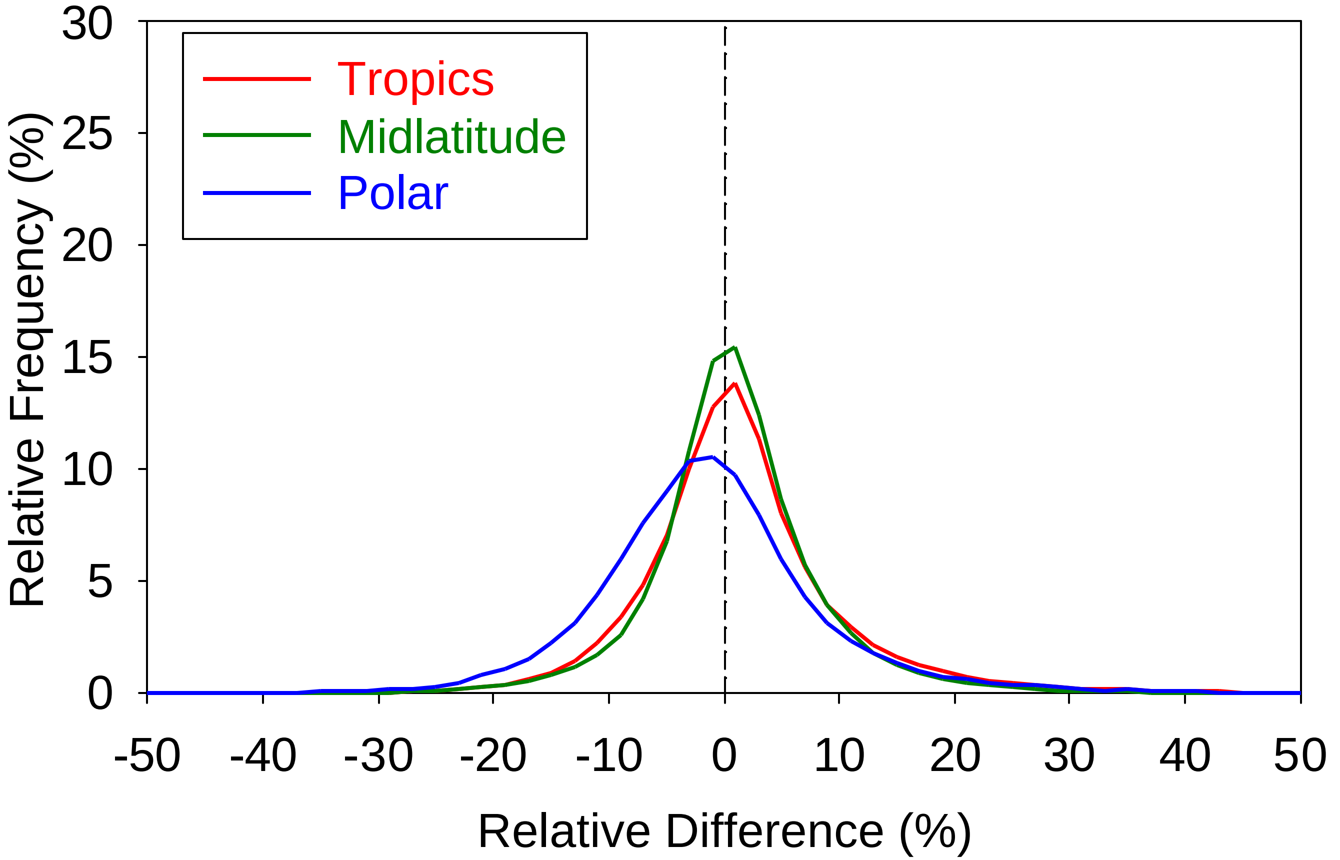
Region	Mean SW Flux (W m^{-2})	Bias (%)	RMS (%)	No. FOVs
Tropics	212.5	-0.4	5.9	35,501
Midlat	155.4	-0.3	9.1	16, 914
Polar	312.6	-12.1	17.7	18,692

Clear-Sky Multiangle Consistency [SW Flux(θ=50°-60°) - SW Flux (Nadir)]



All-Sky Instantaneous SW TOA Flux Consistency: **Terra ADMs**

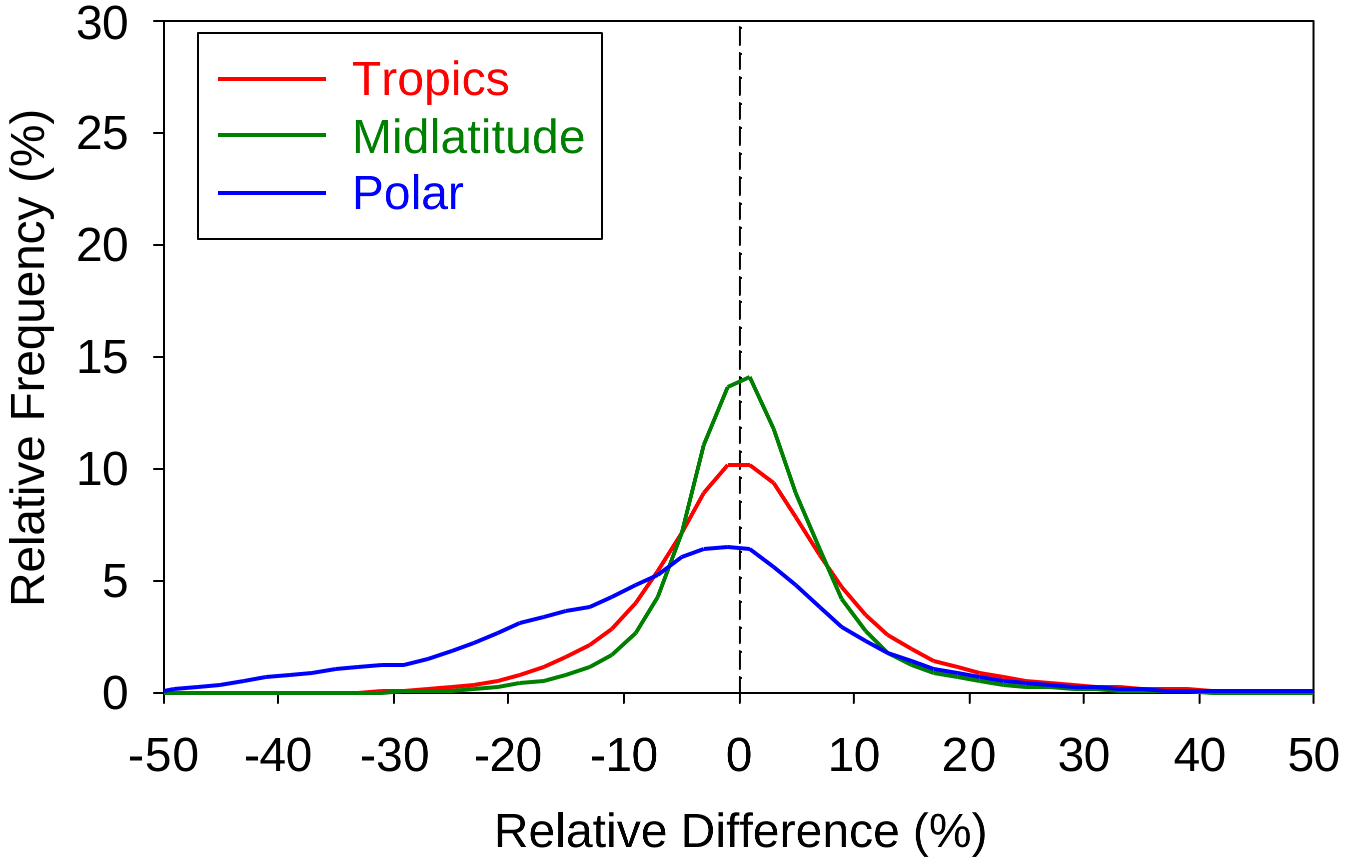
[F(q=50°-60°) - F(Nadir)] / F(Nadir) x 100%



Region	Mean SW Flux ($W\ m^{-2}$)	Bias (%)	RMS (%)	No. FOVs
Tropics	282.6	0.8	8.6	202,639
Midlat	347.4	0.7	6.3	394,018
Polar	292.0	-1.9	9.0	172,998

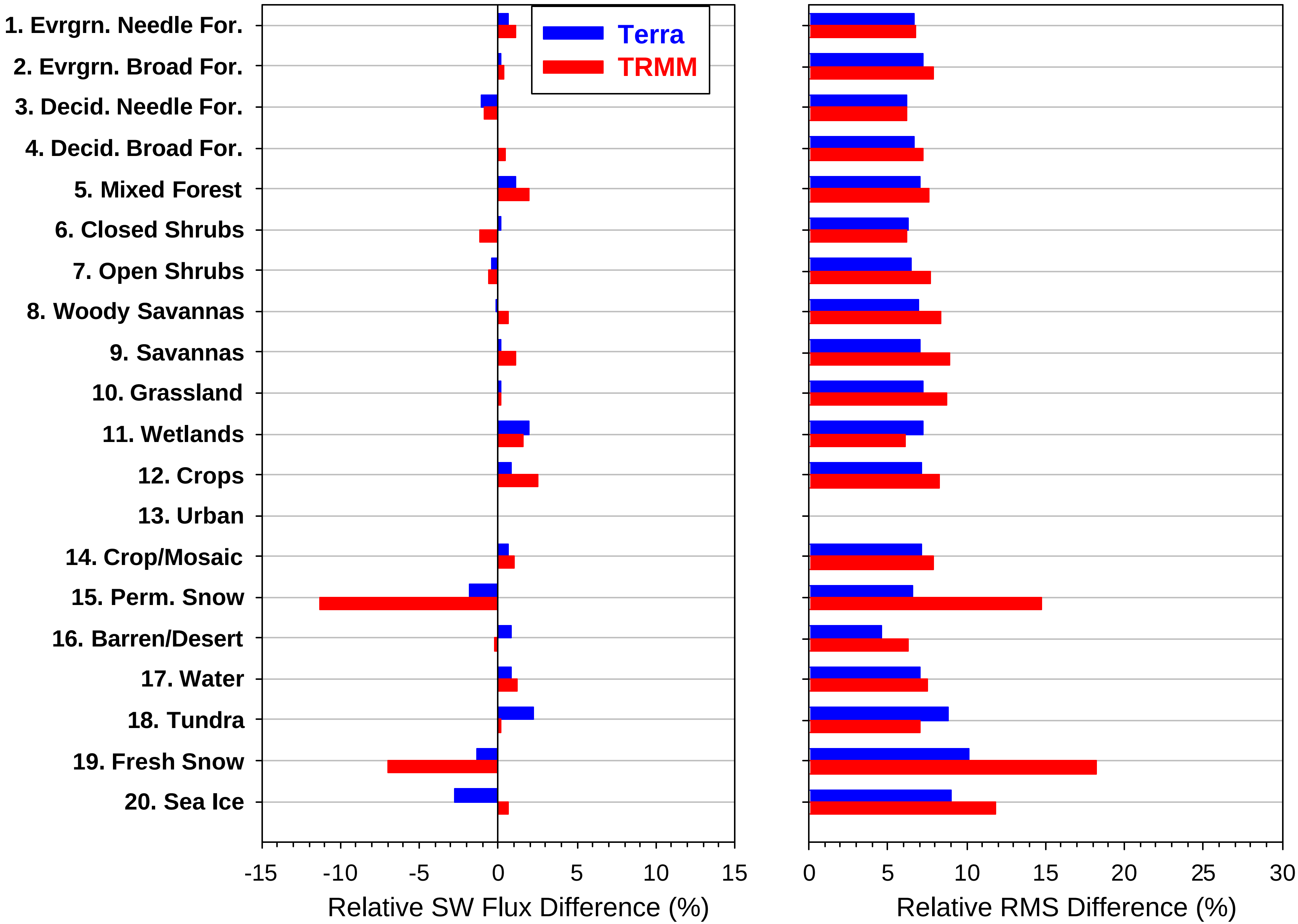
All-Sky Instantaneous SW TOA Flux Consistency: **TRMM ADMs**

[F(q=50°-60°) - F(Nadir)] / F(Nadir) x 100%



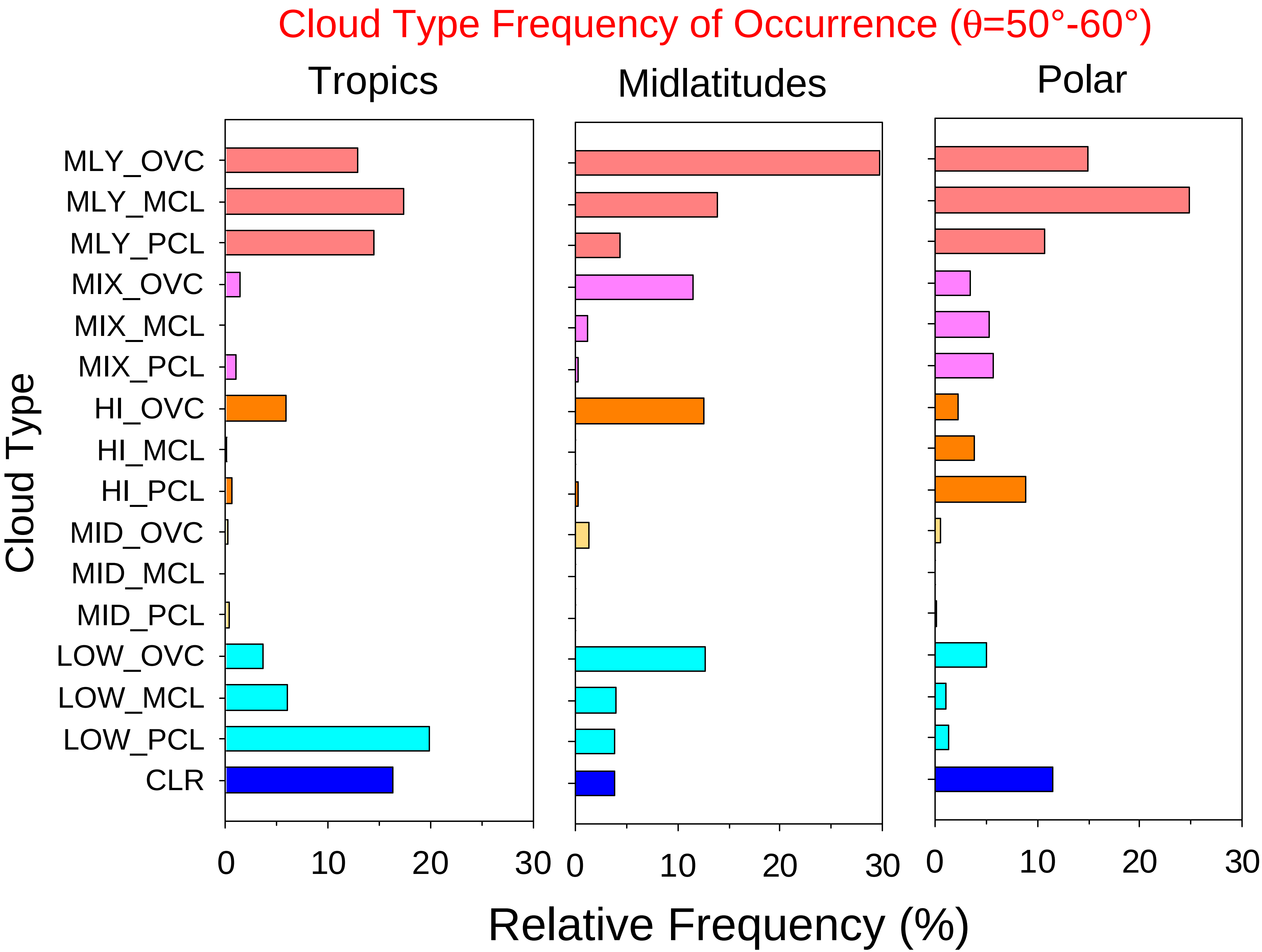
Region	Mean SW Flux ($W\ m^{-2}$)	Bias (%)	RMS (%)	No. FOVs
Tropics	248.8	1.3	10.0	240,414
Midlat	338.3	1.0	6.5	402,846
Polar	298.9	-5.0	14.9	169,418

All-Sky Multiangle Consistency [SW Flux(θ=50°-60°) - SW Flux (Nadir)]



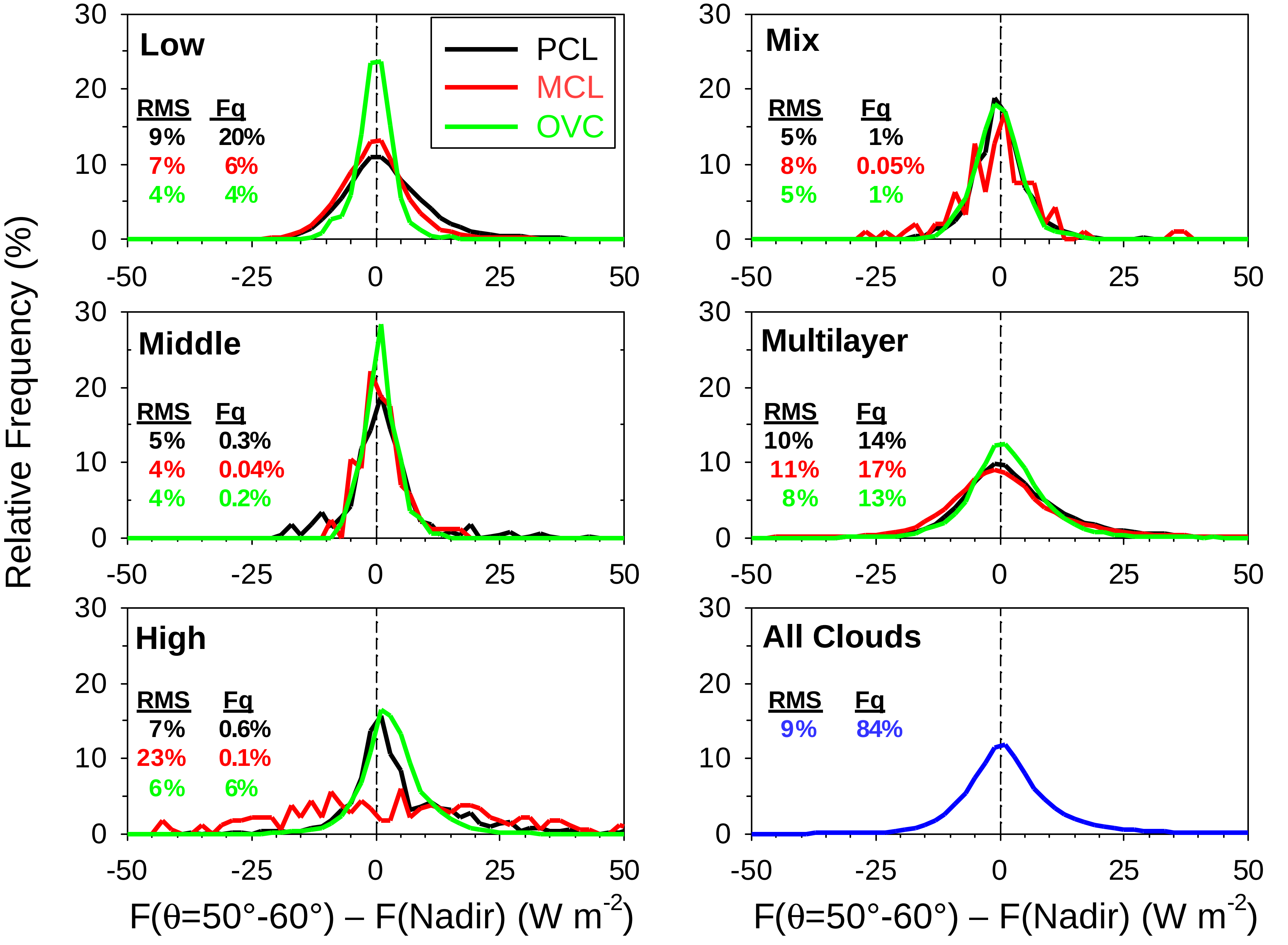
Cloud Types

Cld No.	Cld Type	Z_T (km)	Phase (% Ice)	f (%)
1	Low_PCL	≤ 3	< 5	0.1 – 40
2	Low_MCL	≤ 3	< 5	40 – 99
3	Low_OVC	≤ 3	< 5	> 99
4	Middle_PCL	> 3	< 5	0.1 - 40
5	Middle_MCL	> 3	< 5	40 - 99
6	Middle_OVC	> 3	< 5	> 99
7	High_PCL	-	> 95	0.1 - 40
8	High_MCL	-	> 95	40 - 99
9	High_OVC	-	> 95	> 99
10	Mix_PCL	-	5 - 95	0.1 - 40
11	Mix_MCL	-	5 - 95	40 - 99
12	Mix_OVC	-	5 - 95	> 99
13	Multilayer_PCL	-	-	0.1 - 40
14	Multilayer_MCL	-	-	40 - 99
15	Multilayer_OVC	-	-	> 99

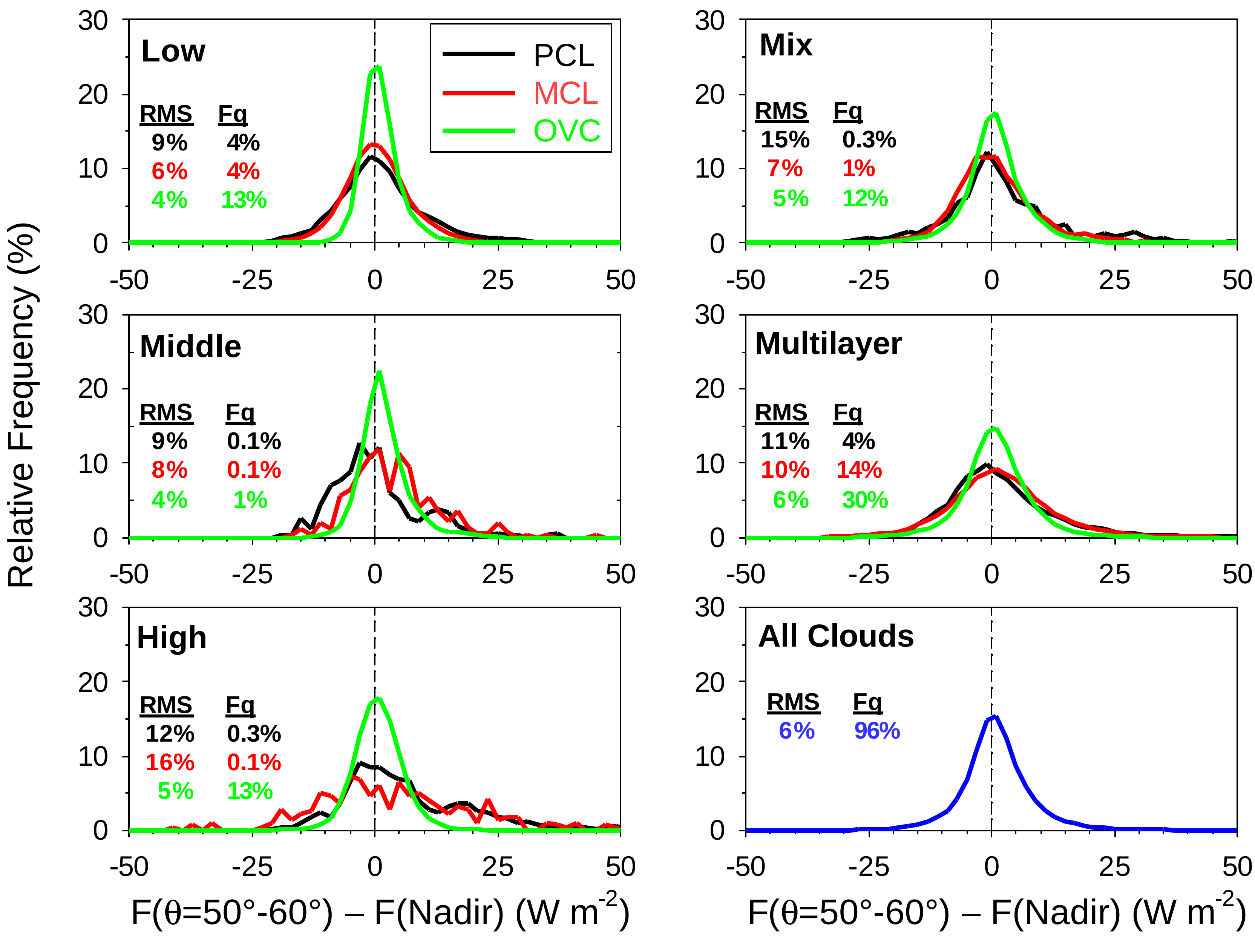


Cloud Type Frequency of Occurrence (θ=50°-60°)
Tropics
Midlatitudes
Polar
MLY_OVC
MLY_MCL
MLY_PCL
MIX_OVC
MIX_MCL
MIX_PCL
HI_OVC
HI_MCL
HI_PCL
MID_OVC
MID_MCL
MID_PCL
LOW_OVC
LOW_MCL
LOW_PCL
CLR
Cloud Type
0
10
20
30
Relative Frequency (%)

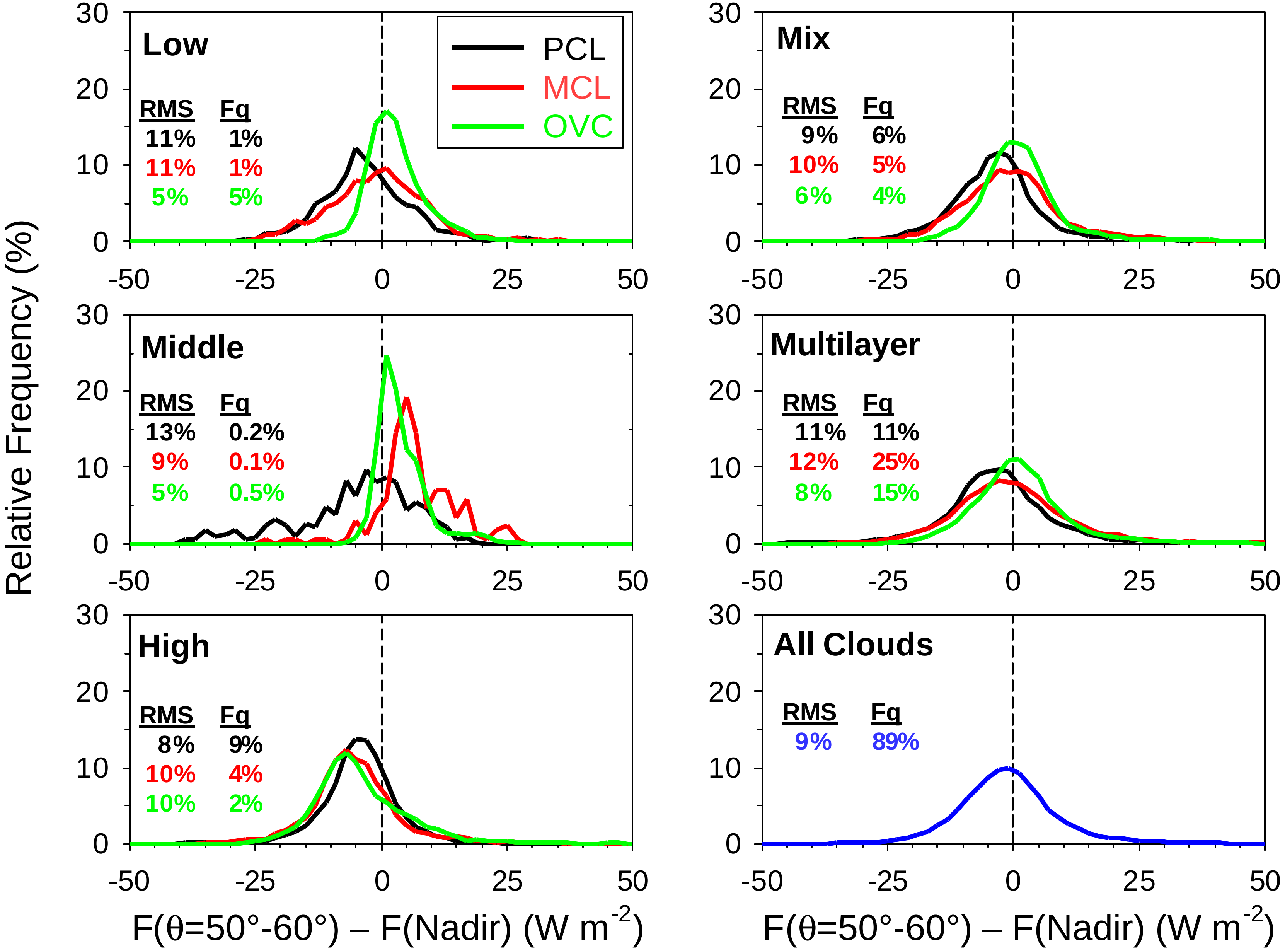
Instantaneous SW TOA Flux Consistency by Cloud Type: **Tropics**



Instantaneous SW TOA Flux Consistency by Cloud Type: **Midlatitudes**

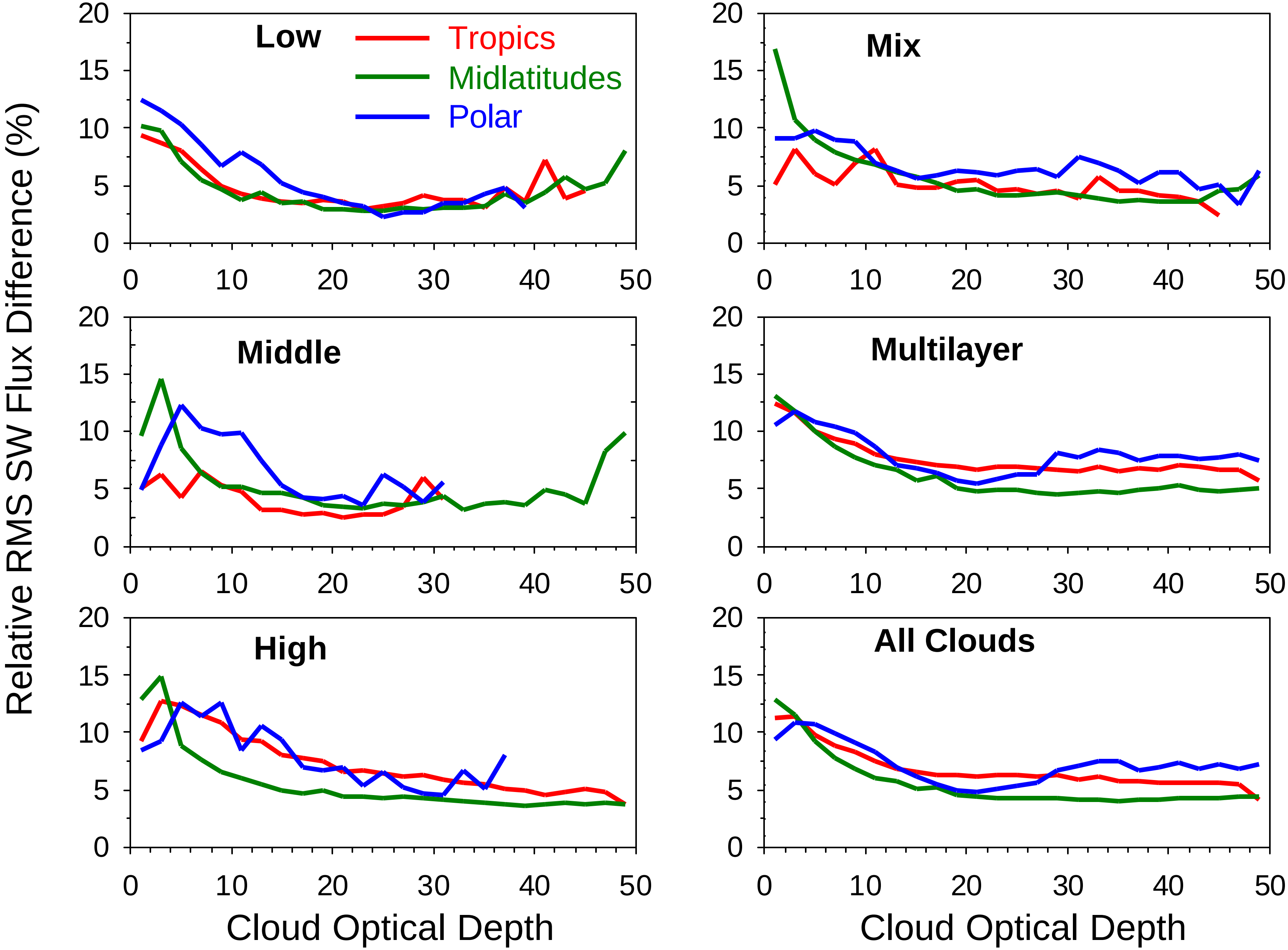


Instantaneous SW TOA Flux Consistency by Cloud Type: **Polar**

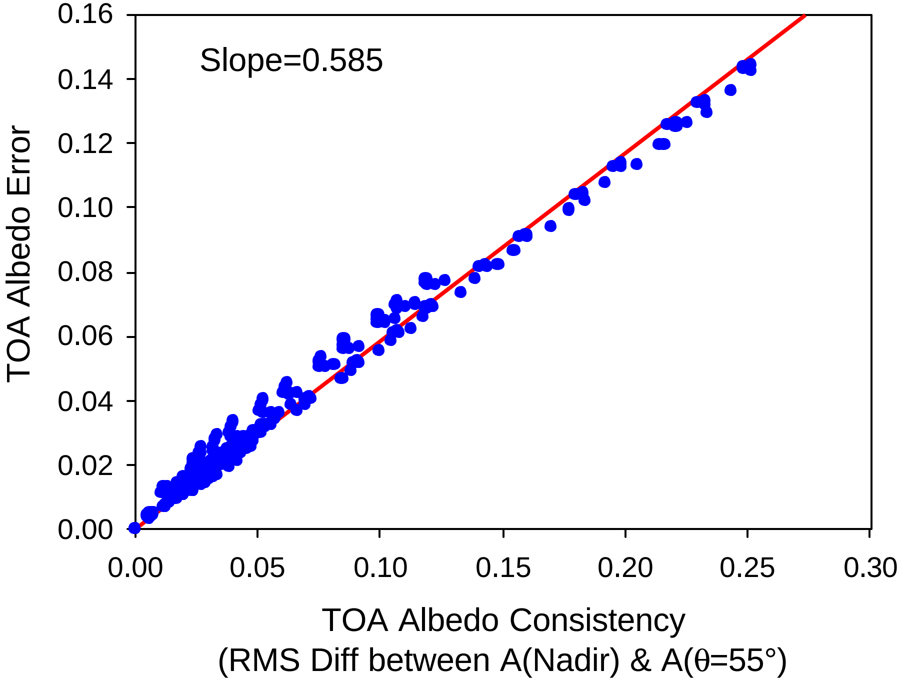


Instantaneous SW TOA Flux Consistency by Cloud Optical Depth

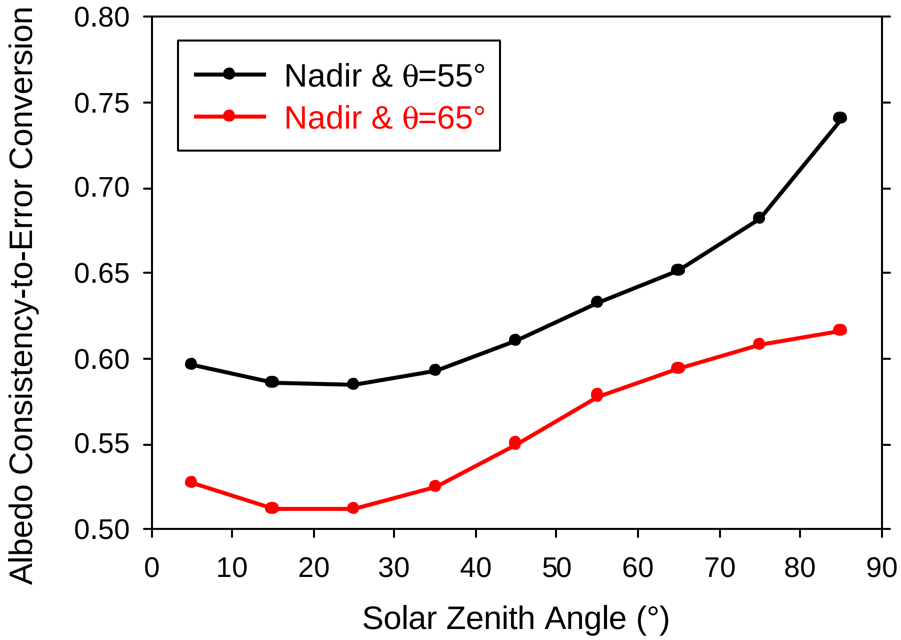
Relative RMS Difference in F(θ=50°-60°) – F(Nadir)



TOA Albedo Error vs Albedo Consistency at Nadir and θ=55°
(3 ADMs Applied to 1D Cloud Popln; θ_o=20°-30°)



Albedo Consistency-to-Error Conversion vs θ_o



Estimated Instantaneous TOA Flux Error

Region	S_o (W m^{-2})	Terra ADMs W m^{-2} (%)		TRMM ADMs W m^{-2} (%)	
		Clear	All-sky	Clear	All-sky
Tropics	1150	5.2 (2.2)	14.3 (5.1)	7.7 (3.5)	14.3 (5.8)
Midlat	870	4.2 (3.0)	13.5 (3.9)	7.3 (5.6)	13.7 (4.1)
Polar	540	12.8 (4.3)	17.3 (5.9)	37.0 (11.7)	29.2 (9.8)

LW TOA Flux Validation

1) Direct Integration Test

2) TOA flux differences between CERES/Terra ED1 and ED2

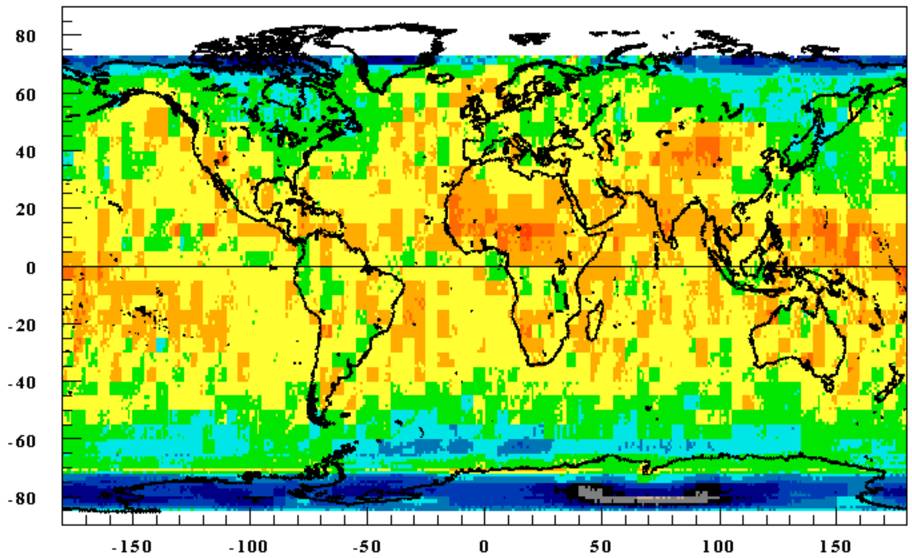
3) ES8 – ED2 TOA flux differences

4) Alongtrack Consistency Tests

All-Sky **Daytime** Longwave Flux Direct Integration Tests (DJF)

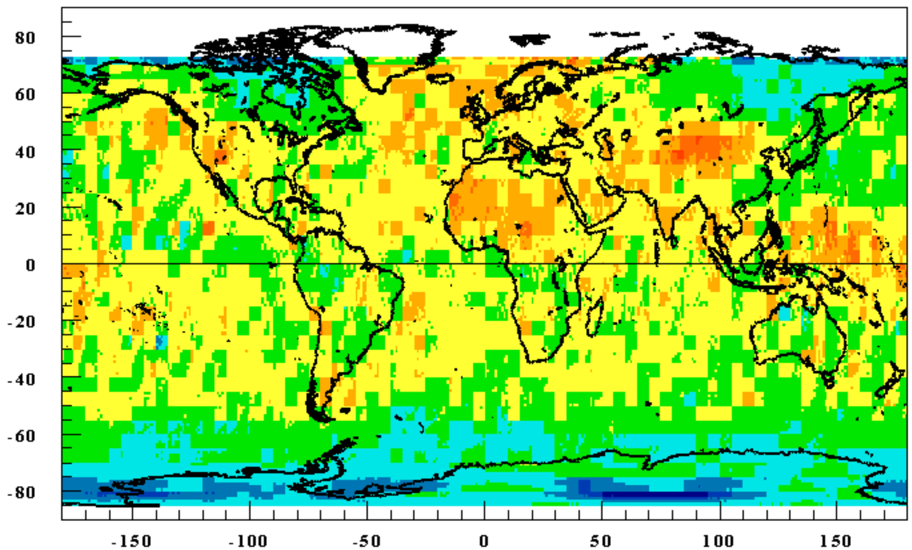
TRMM ADMs
F(ADM) – F(DI)

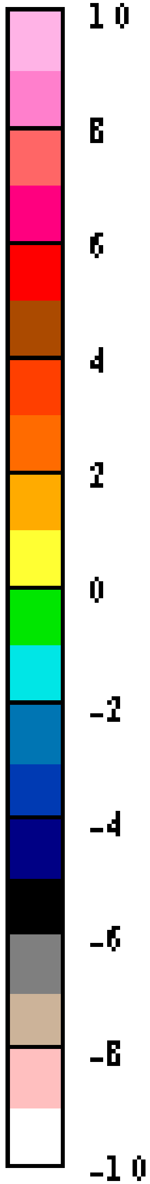
MN DIFF
-0.13 W m^{-2}
RMS Diff
1.45 W m^{-2}



Terra ADMs
F(ADM) – F(DI)

MN DIFF
-0.04 W m^{-2}
RMS Diff
0.93 W m^{-2}



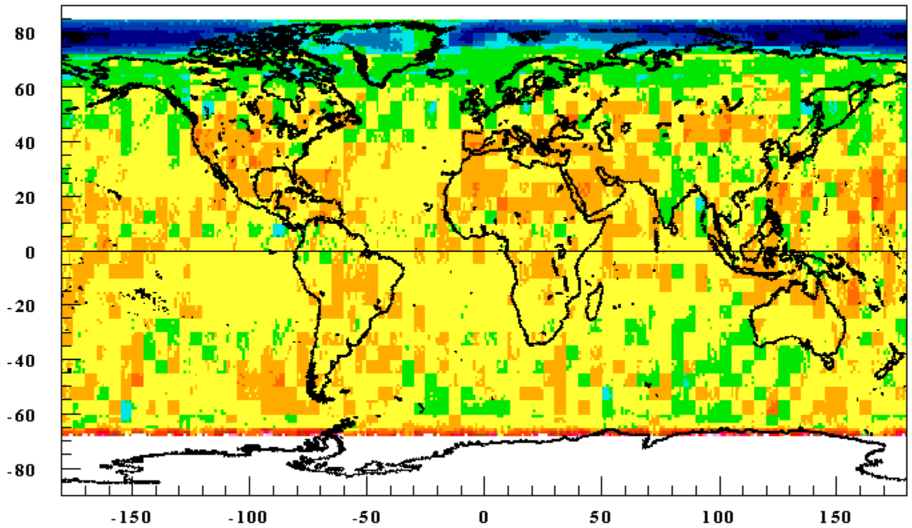


Flux Error
(W m^{-2})

All-Sky **Daytime** Longwave Flux Direct Integration Tests (JJA)

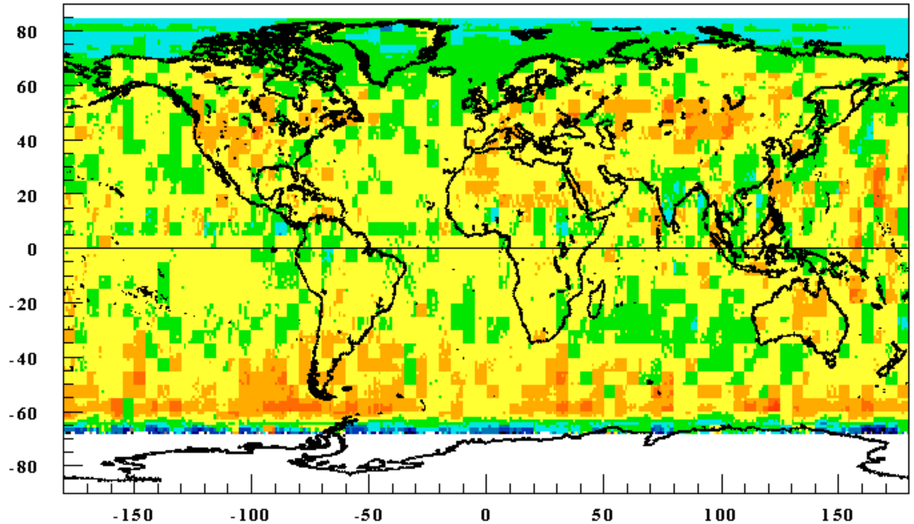
TRMM ADMs
F(ADM) – F(DI)

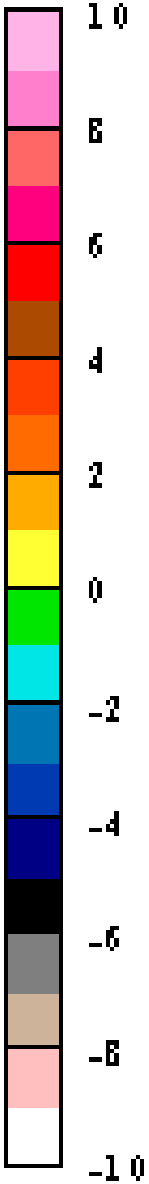
MN DIFF
0.35 W m^{-2}
RMS Diff
1.32 W m^{-2}



Terra ADMs
F(ADM) – F(DI)

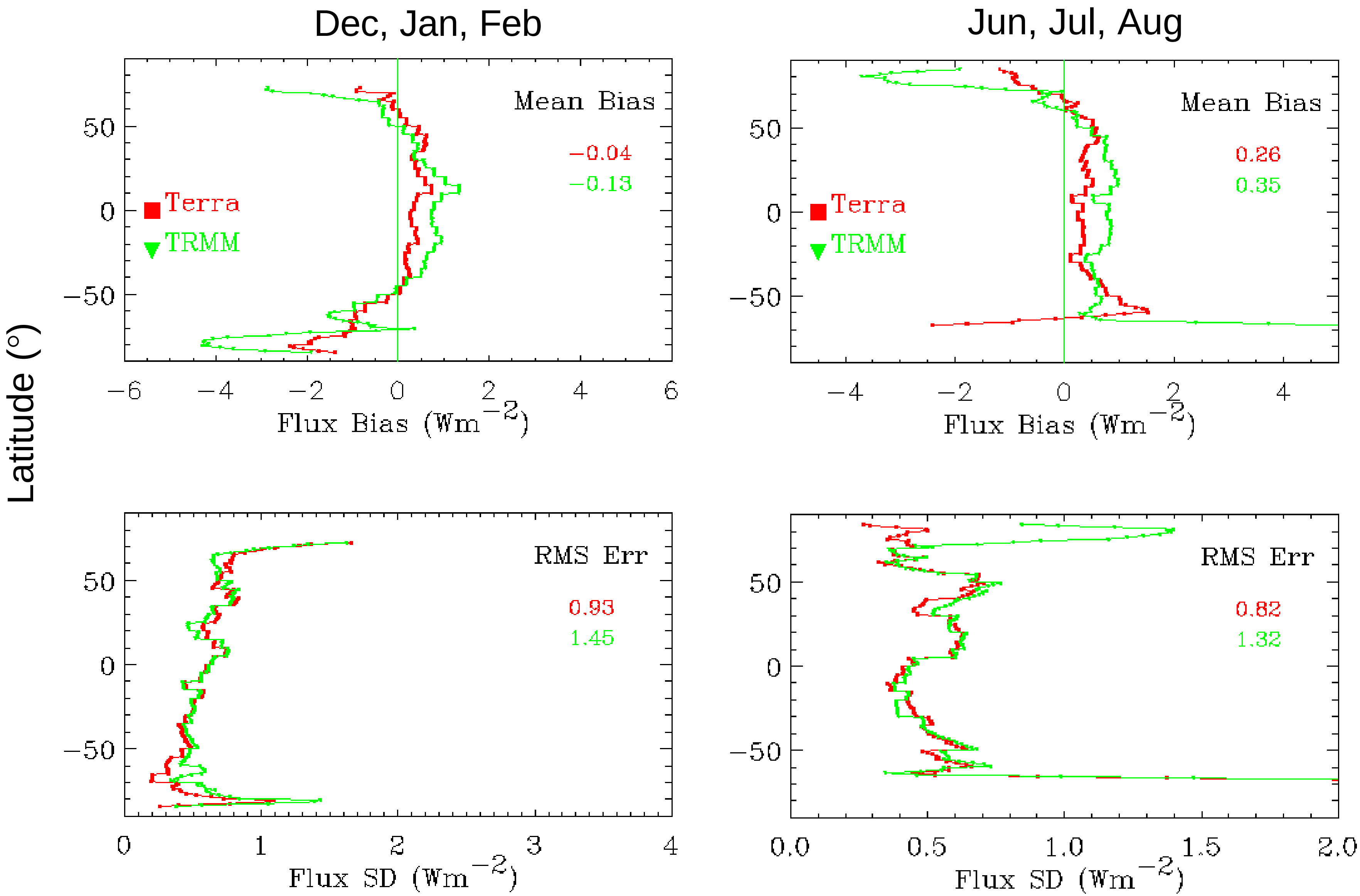
MN DIFF
0.26 W m^{-2}
RMS Diff
0.82 W m^{-2}





Flux Error
(W m^{-2})

Daytime LW Flux Difference (F(ADM) - F(DI))



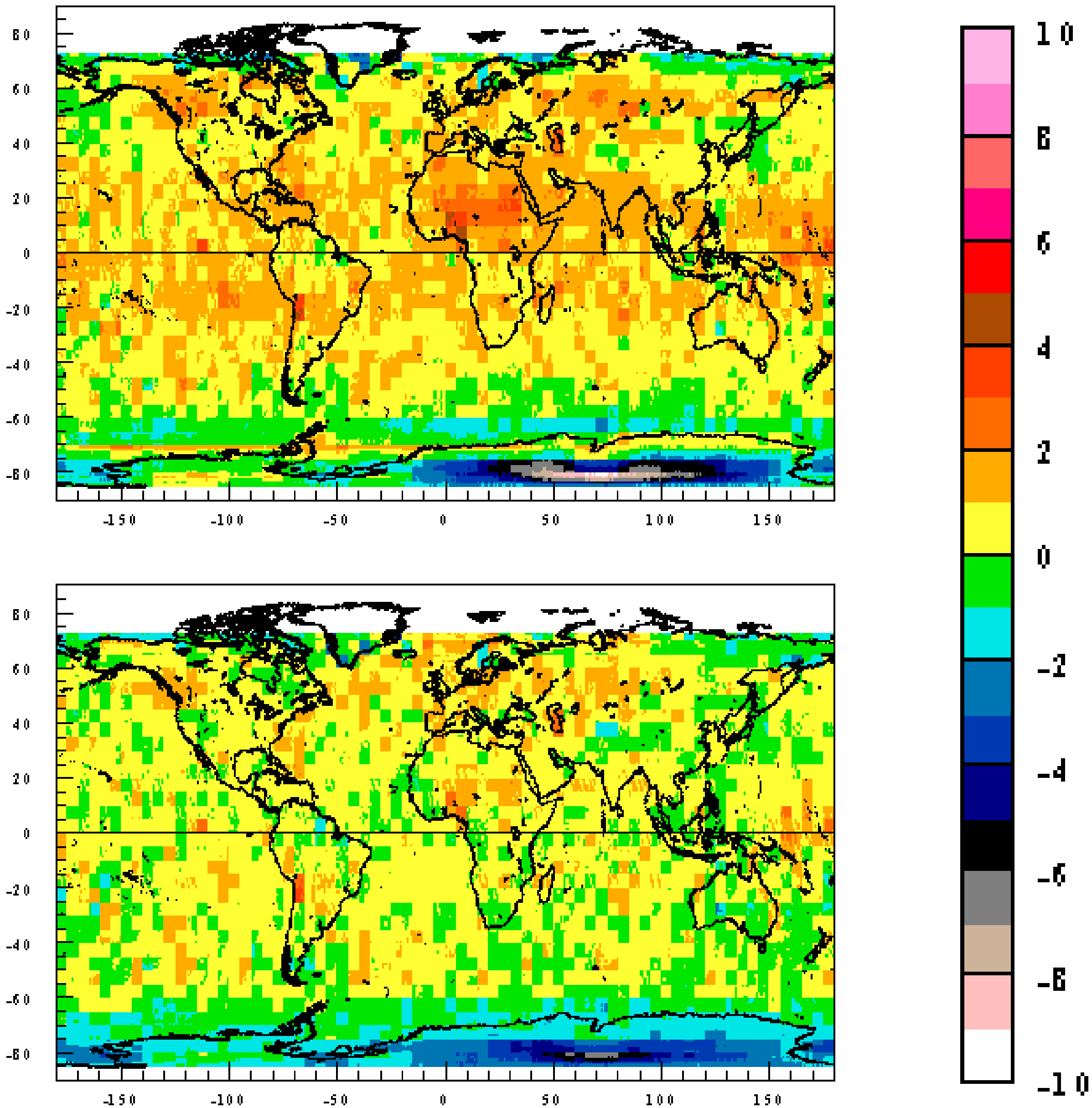
All-Sky **Nighttime** Longwave Flux Direct Integration Tests (DJF)

TRMM ADMs
F(ADM) – F(DI)

MN DIFF
0.28 W m^{-2}
RMS Diff
1.63 W m^{-2}

Terra ADMs
F(ADM) – F(DI)

MN DIFF
-0.10 W m^{-2}
RMS Diff
1.34 W m^{-2}



Flux Error
(W m^{-2})

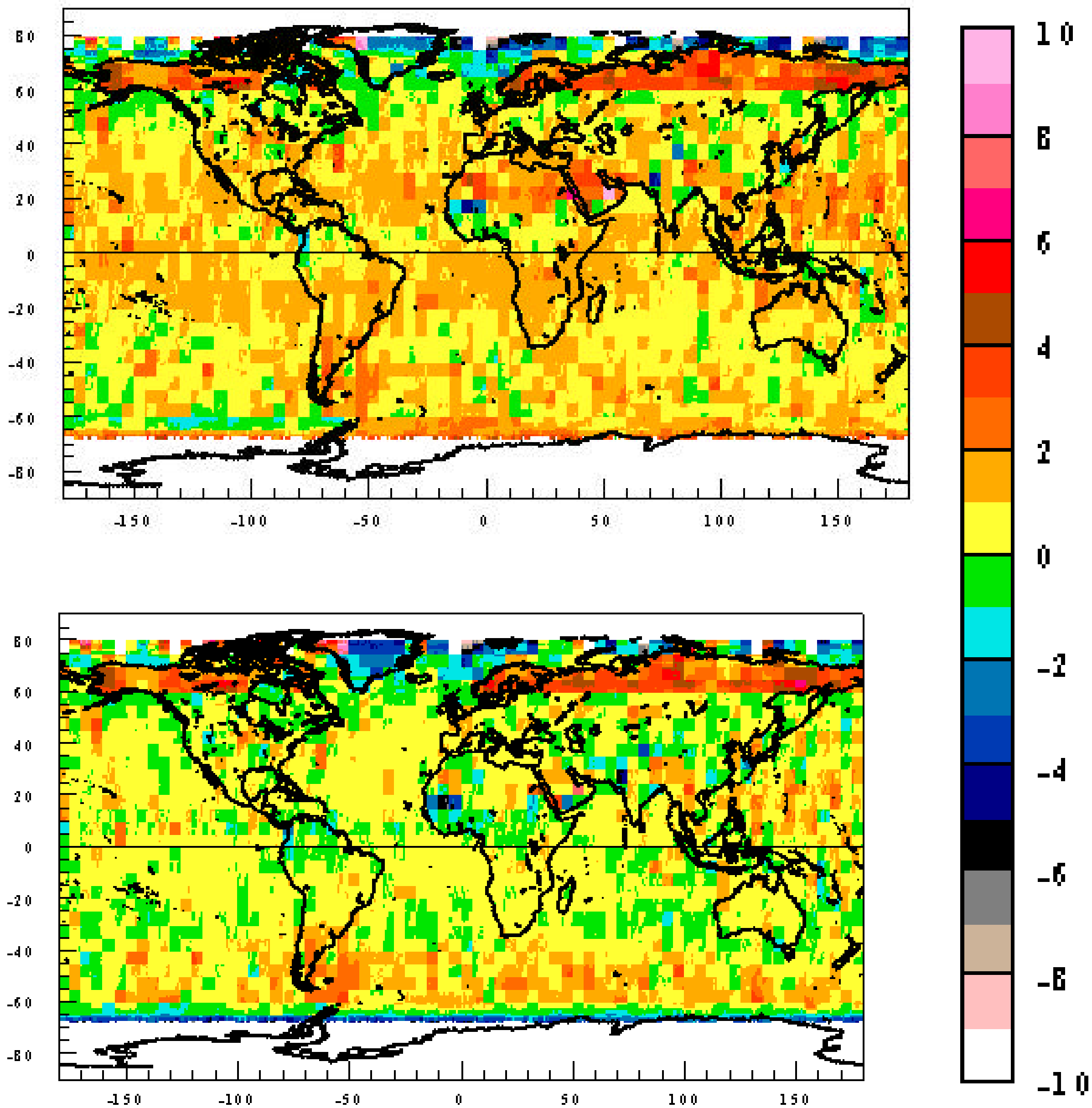
All-Sky **Nighttime** Longwave Flux Direct Integration Tests (JJA)

TRMM ADMs
F(ADM) – F(DI)

MN DIFF
0.69 W m^{-2}
RMS Diff
1.37 W m^{-2}

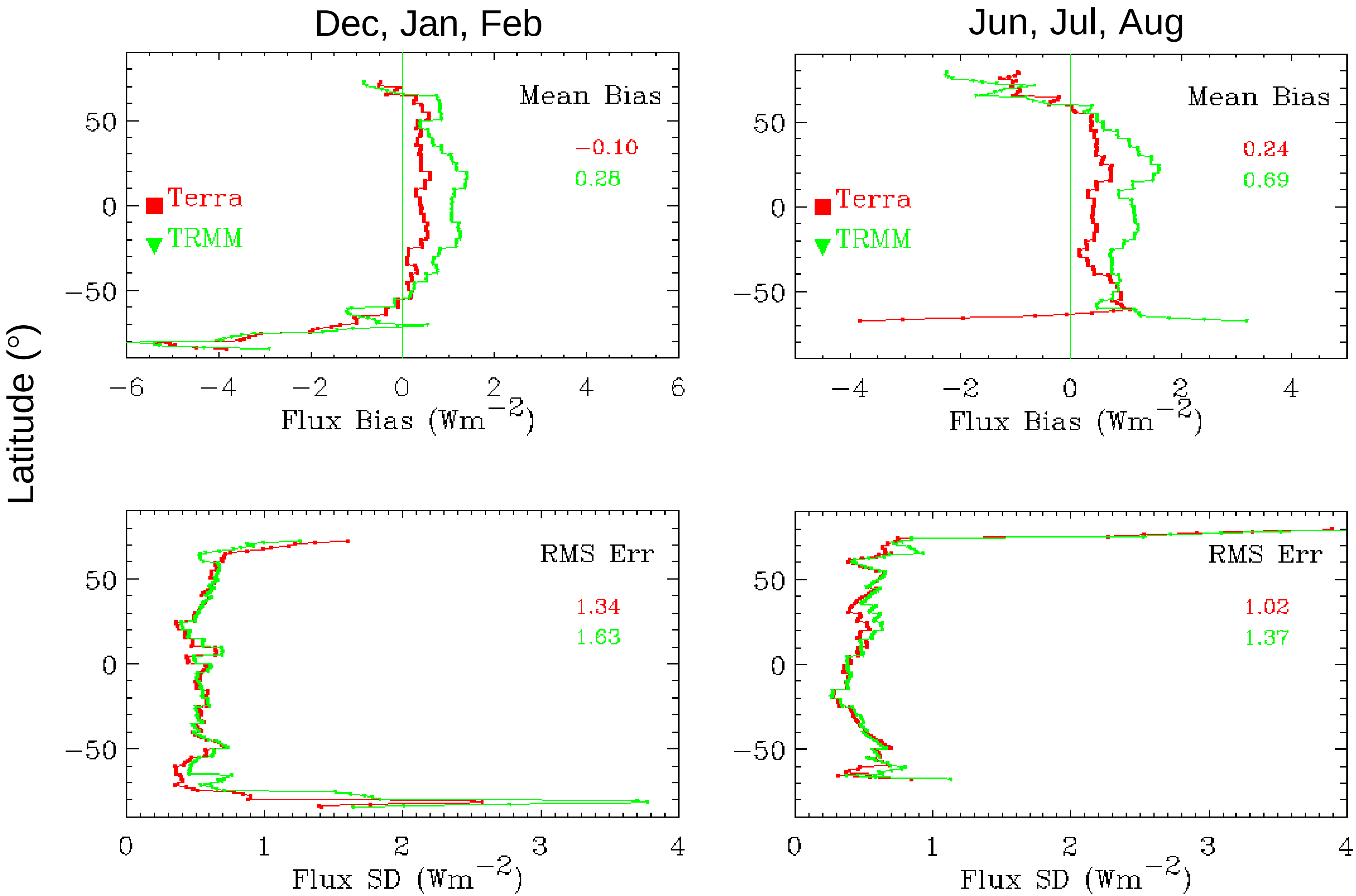
Terra ADMs
F(ADM) – F(DI)

MN DIFF
0.24 W m^{-2}
RMS Diff
1.02 W m^{-2}



Flux Error (W m^{-2})

Nighttime LW Flux Difference (F(ADM) - F(DI))



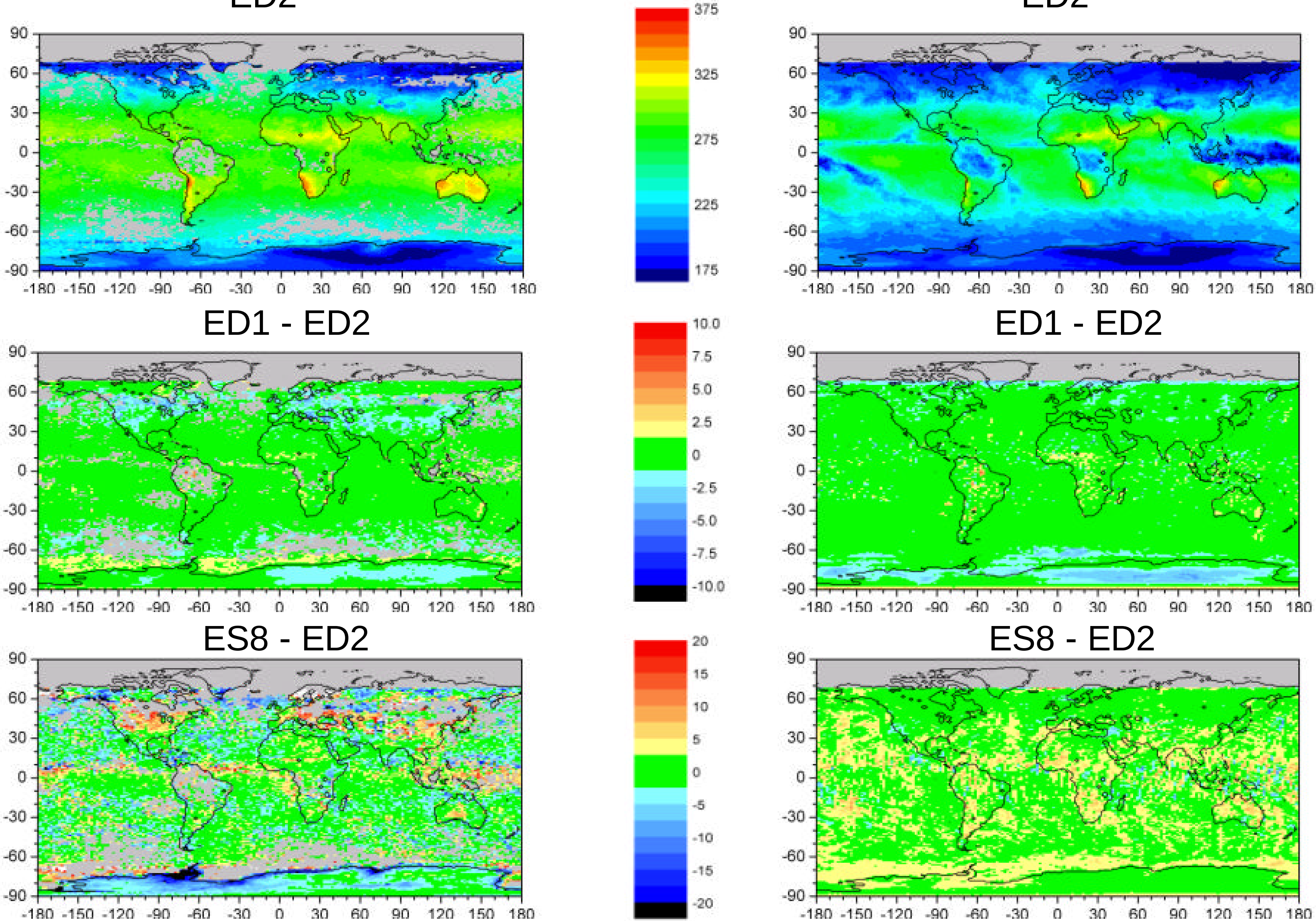
All-Sky LW TOA Flux Direct Integration Results

	Terra ADMs		TRMM ADMs	
	Avg Diff	RMS Diff	Avg Diff	RMS Diff
DJF (Day)	-0.04	0.93	-0.13	1.45
DJF (Night)	-0.10	1.34	0.28	1.63
JJA (Day)	0.26	0.82	0.35	1.32
JJA (Night)	0.24	1.02	0.69	1.37

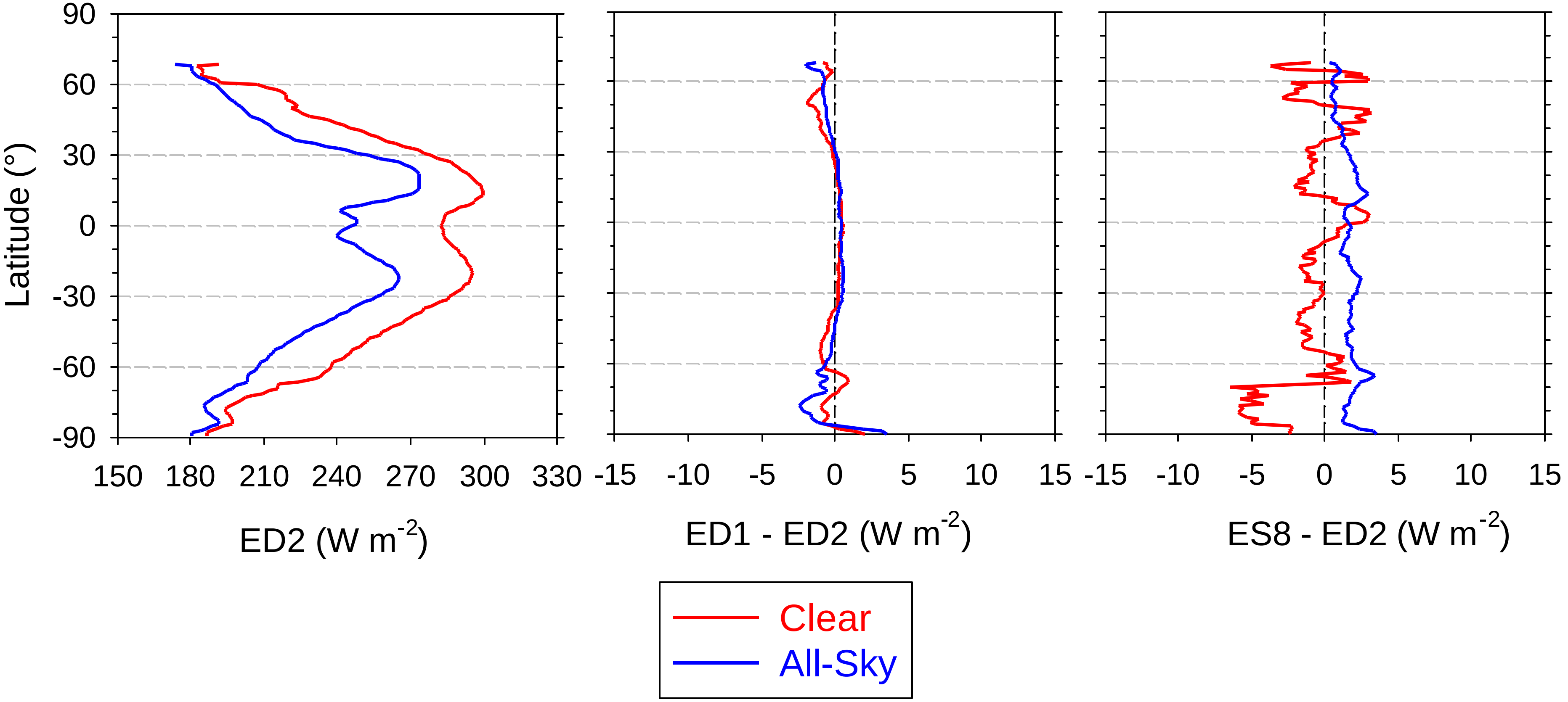
LW Daytime TOA Flux Comparisons

DECEMBER, 2001

CLEAR-SKY ED2 | All-SKY ED2

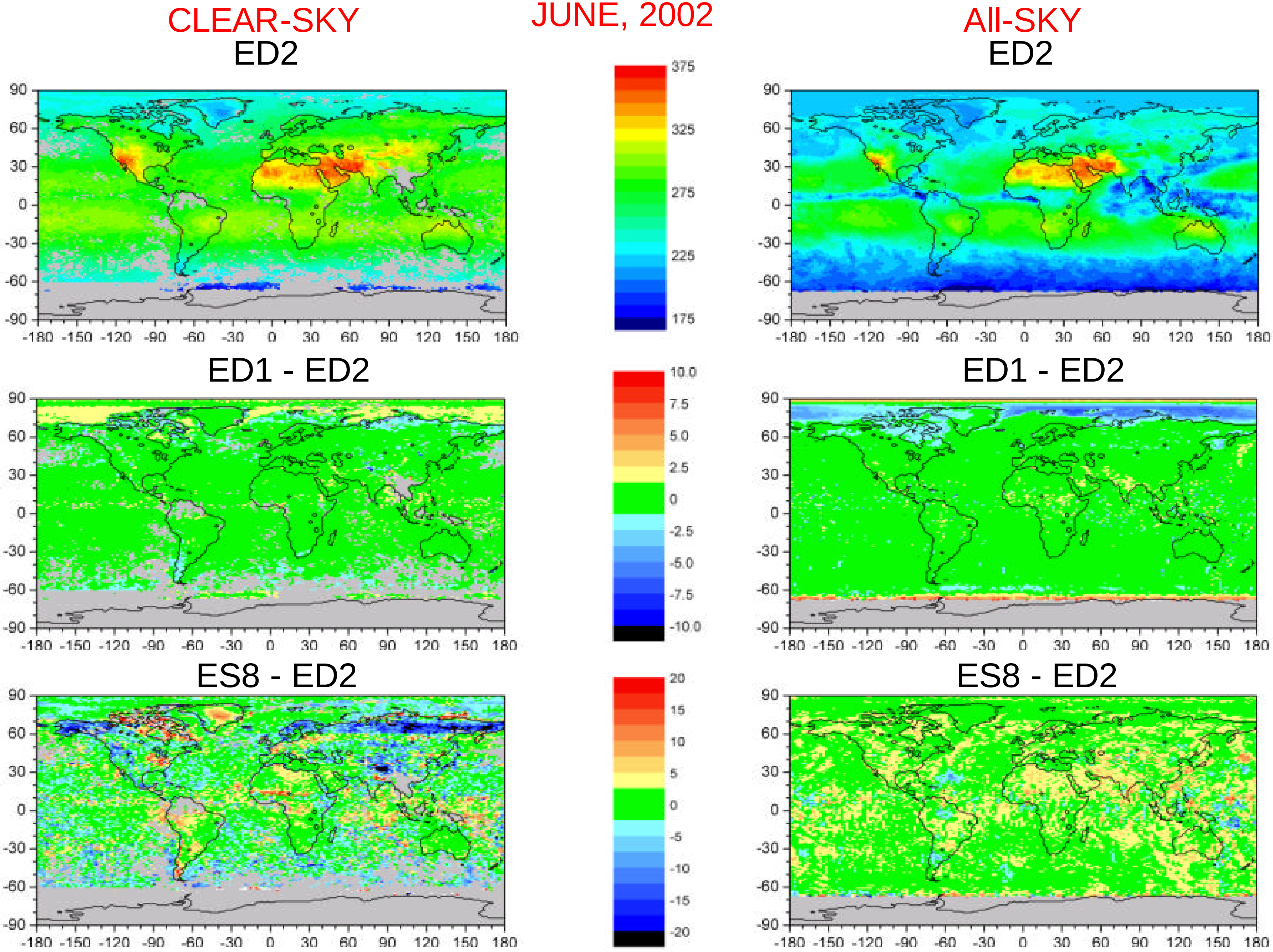


LW TOA Flux Comparison (December 2001)

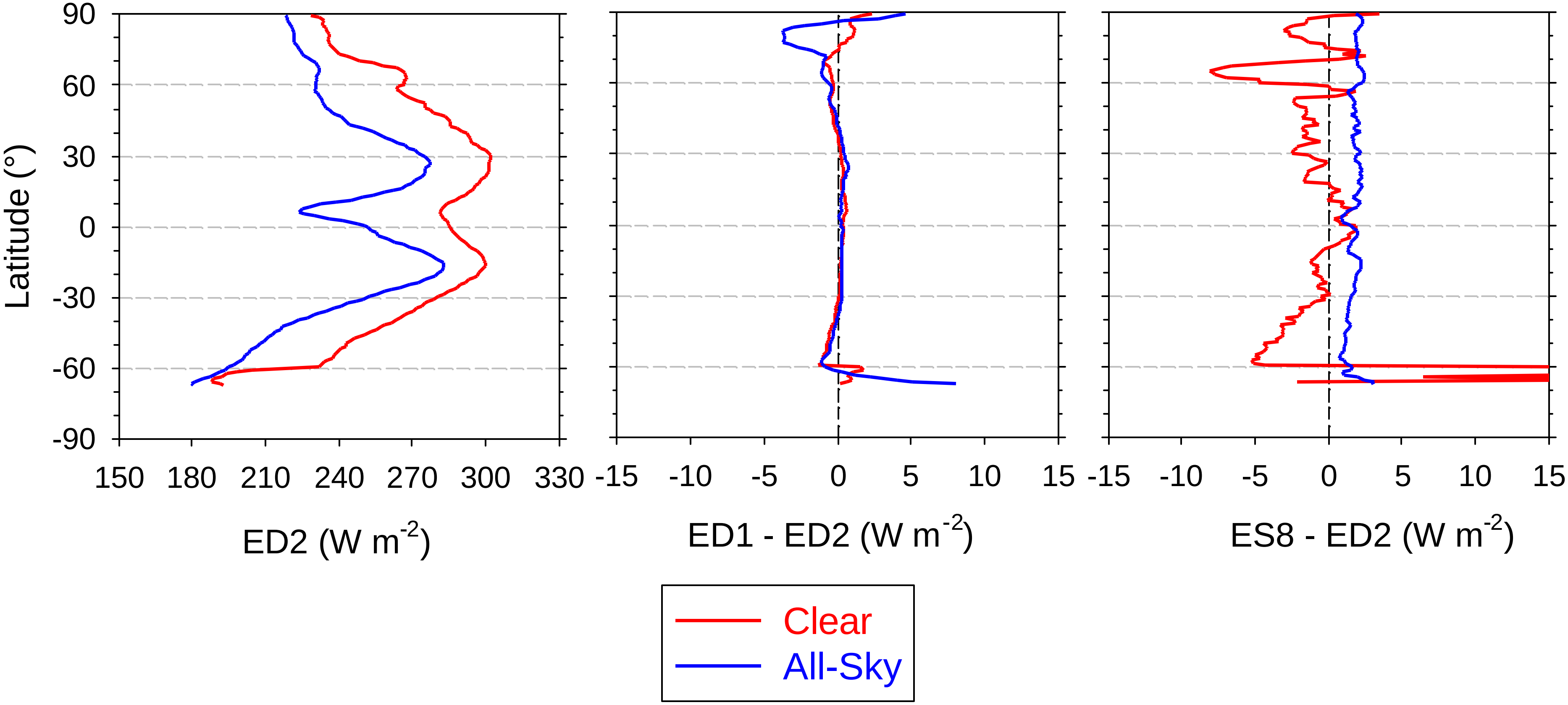


LW Daytime TOA Flux Comparisons

JUNE, 2002



LW TOA Flux Comparison (June 2002)



Daytime LW TOA Flux Differences: ES8 & ED1 vs ED2 (December 2001)

	Avg	Avg Diff		RMS Diff		
				1°-Regional		FOV
	ED2	ES8 vs ED2	ED1 vs ED2	ES8 vs ED2	ED1 vs ED2	ED1 vs ED2
Clear (30°S-30°N)	290.4	-0.2	0.3	4.2	0.6	0.9
All-Sky (30°S-30°N)	257.6	1.9	0.4	3.1	0.8	2.5
Clear (Global)	267.1	-0.3	-0.1	5.6	0.8	1.2
All-Sky (Global)	237.5	1.6	0.0	2.7	0.6	2.8

Notes: i) Diff = LW Flux(ES8) – LW Flux(ED2) or LW Flux(ED1) – LW Flux(ED2)
ii) All fluxes in W m^{-2}

Nighttime LW TOA Flux Differences: ED1 vs ED2 (December 2001)

	Avg	Avg Dif	RMS Diff	
			1°-Regional	FOV
	ED2	ED1 vs ED2	ED1 vs ED2	ED1 vs ED2
Clear (30°S-30°N)	285.8	0.1	0.5	0.8
All-Sky (30°S-30°N)	251.7	1.1	1.7	3.0
Clear (Global)	260.8	0.1	0.8	1.2
All-Sky (Global)	233.6	1.1	1.3	3.1

Notes: i) Diff = LW Flux(ED1) – LW Flux(ED2)
ii) All fluxes in W m^{-2}

Daytime LW TOA Flux Differences: ES8 & ED1 vs ED2 (June 2002)

	Avg	Avg Diff		RMS Diff		
				1°-Regional		FOV
	ED2	ES8 vs ED2	ED1 vs ED2	ES8 vs ED2	ED1 vs ED2	ED1 vs ED2
Clear (30°S-30°N)	292.2	0.0	0.3	4.2	0.6	0.9
All-Sky (30°S-30°N)	262.1	1.8	0.3	3.2	0.8	2.4
Clear (Global)	278.4	-0.6	0.1	5.5	0.7	1.1
All-Sky (Global)	246.8	1.7	0.1	3.1	0.7	2.8

Notes: i) Diff = LW Flux(ES8) – LW Flux(ED2) or LW Flux(ED1) – LW Flux(ED2)

ii) All fluxes in W m^{-2}

Nighttime LW TOA Flux Differences: ES8 & ED1 vs ED2 (June 2002)

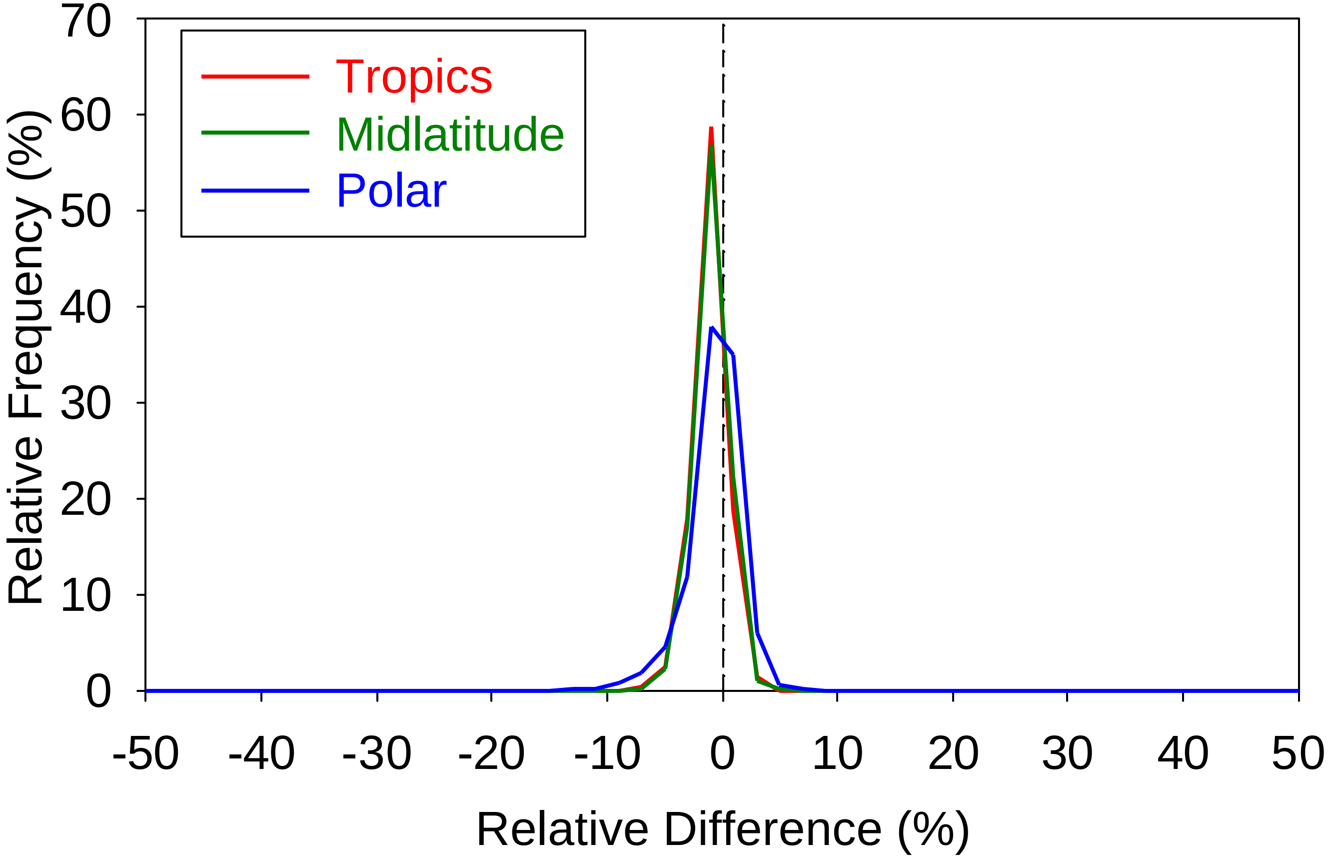
	Avg	Avg Dif	RMS Diff	
			1°-Regional	FOV
	ED2	ED1 vs ED2	ED1 vs ED2	ED1 vs ED2
Clear (30°S-30°N)	287.3	0.2	0.6	0.9
All-Sky (30°S-30°N)	255.5	1.0	1.3	3.0
Clear (Global)	268.6	0.1	0.8	1.1
All-Sky (Global)	238.8	1.0	1.3	3.1

Notes: i) Diff = LW Flux(ED1) – LW Flux(ED2)

ii) All fluxes in W m^{-2}

Clear-Sky Instantaneous LW TOA Flux Consistency: **Terra ADMs**

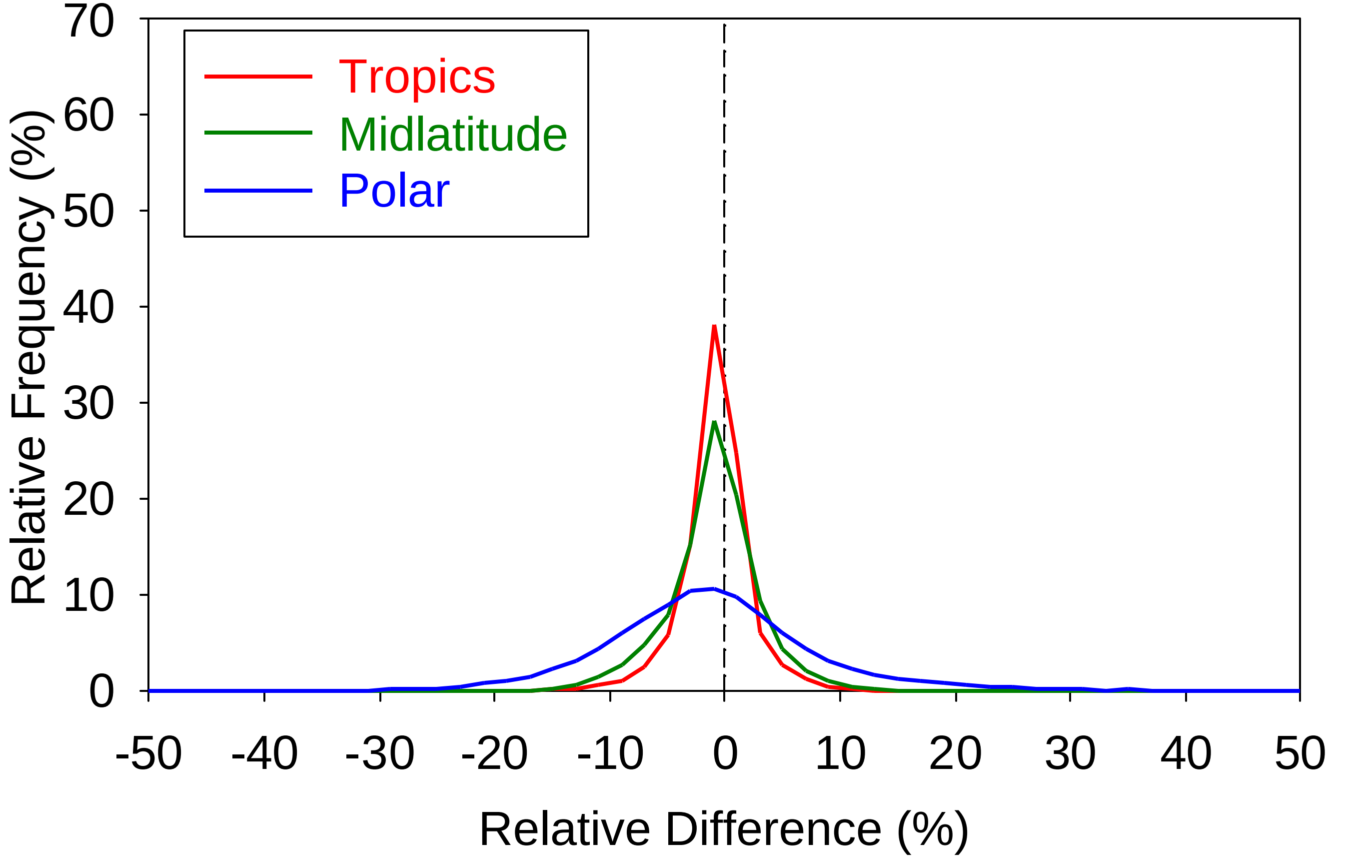
[F(q=50°-60°) - F(Nadir)] / F(Nadir) x 100%



Region	Mean SW Flux ($W\ m^{-2}$)	Bias (%)	RMS (%)	No. FOVs
Tropics	307.3	-1.1	1.8	38,830
Midlat	285.5	-0.9	1.7	23,929
Polar	204.1	-0.8	2.7	17,520

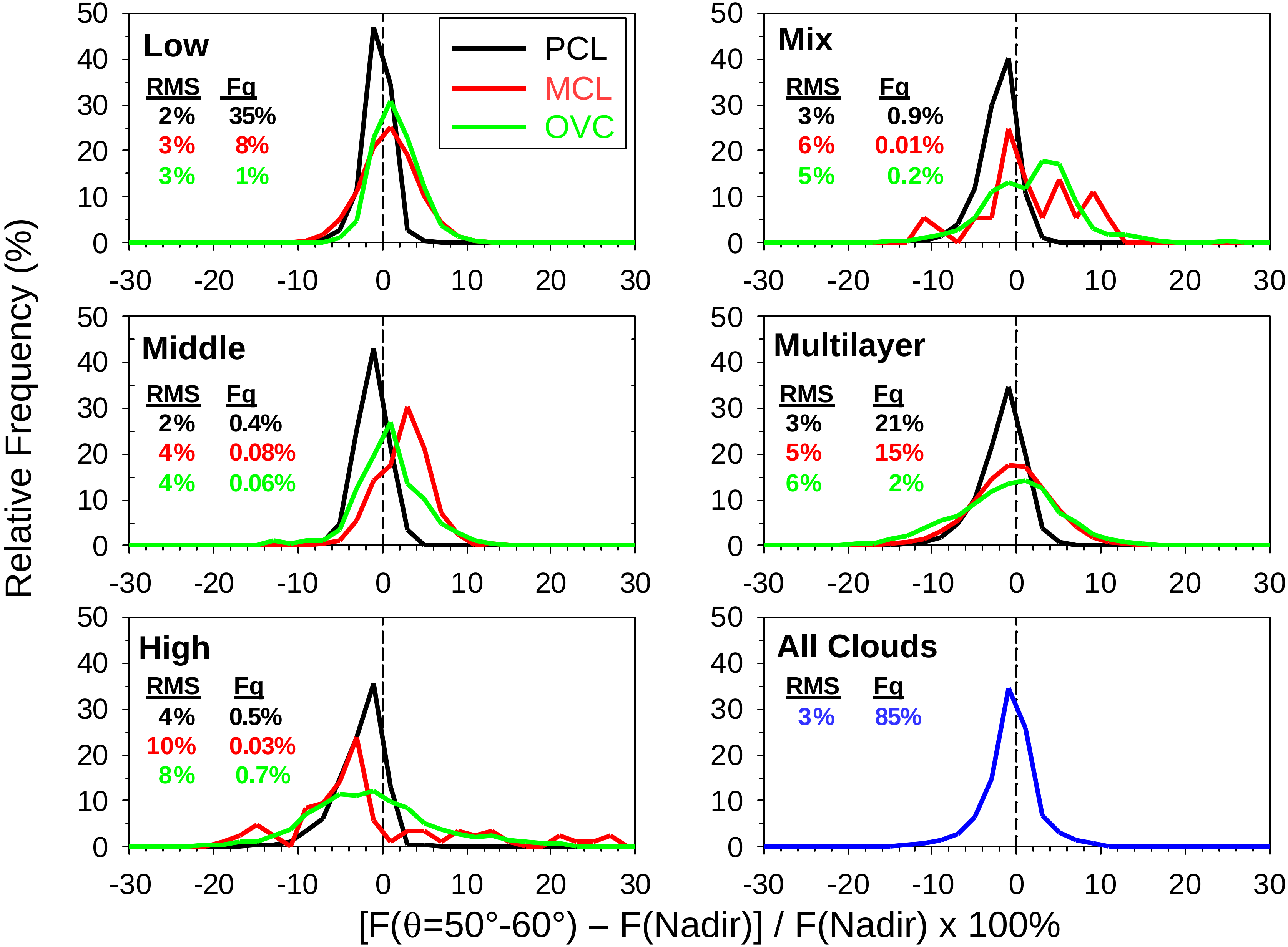
All-Sky Instantaneous LW TOA Flux Consistency: **Terra ADMs**

[F(q=50°-60°) - F(Nadir)] / F(Nadir) x 100%

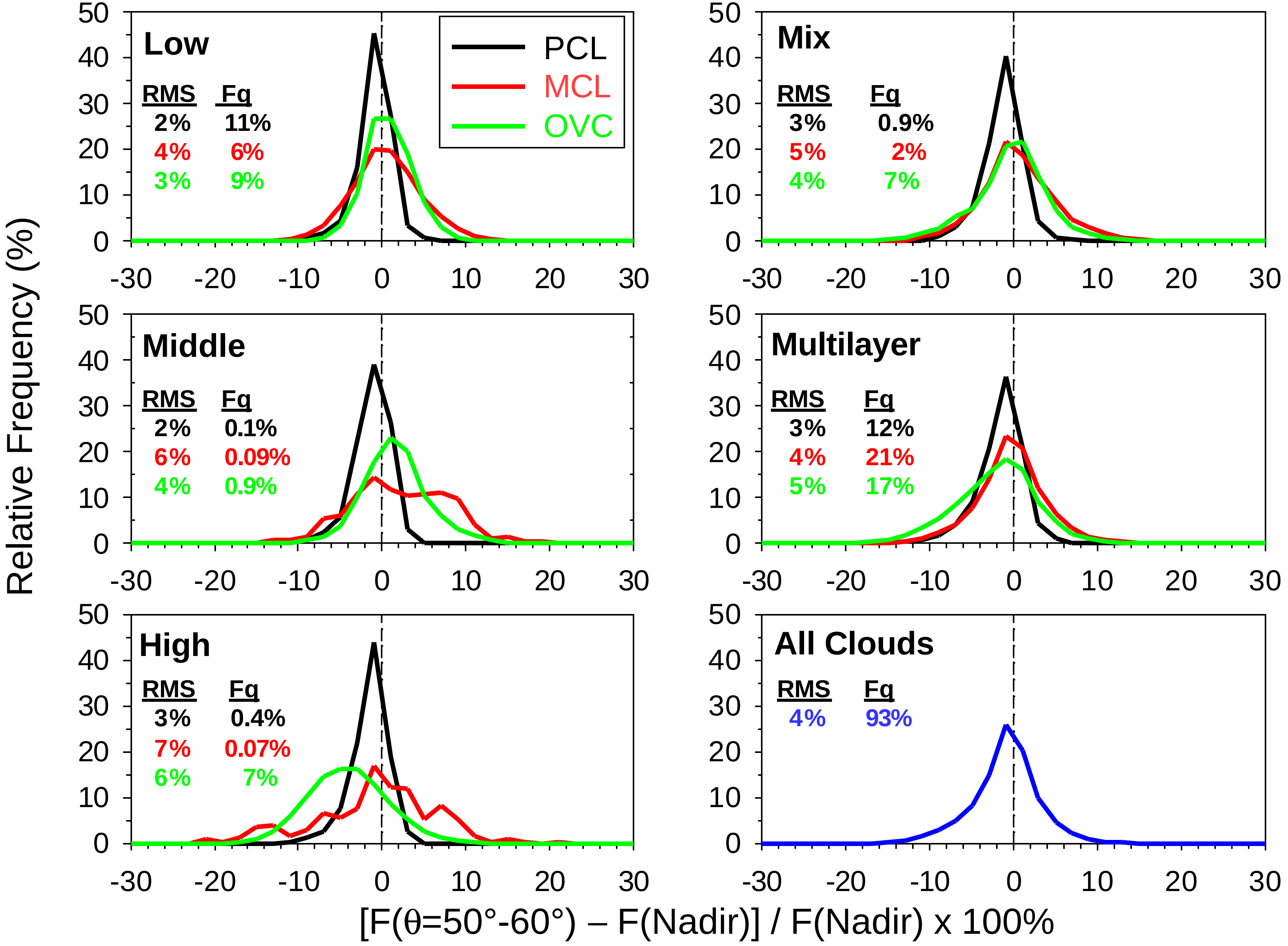


Region	Mean SW Flux ($W\ m^{-2}$)	Bias (%)	RMS (%)	No. FOVs
Tropics	282.2	-0.8	3.0	266,246
Midlat	234.3	-0.9	3.8	340,387
Polar	200.5	-0.6	3.3	147,239

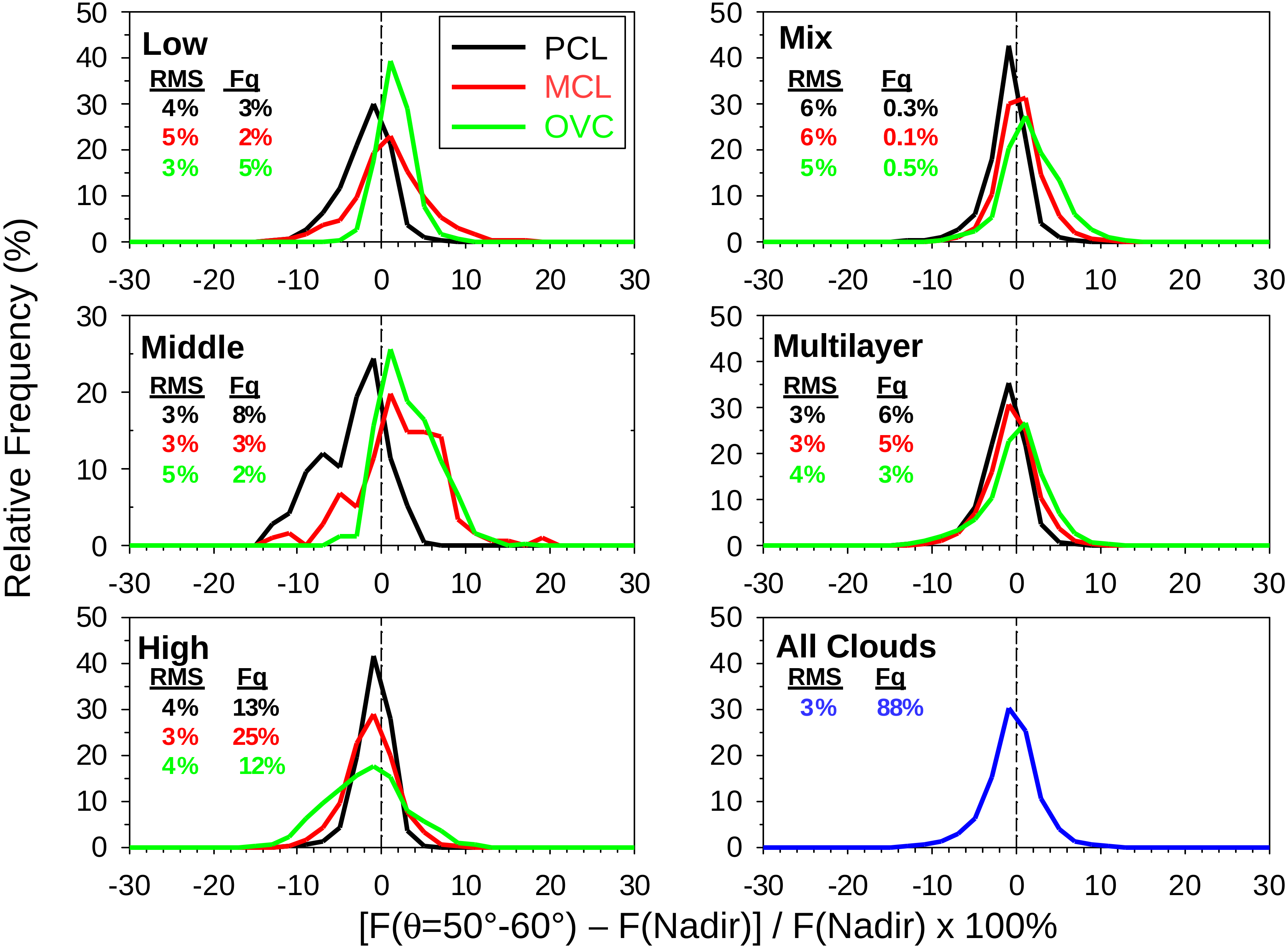
Instantaneous LW TOA Flux Consistency by Cloud Type: **Tropics**



Instantaneous LW TOA Flux Consistency by Cloud Type: Midlatitude



Instantaneous LW TOA Flux Consistency by Cloud Type: Polar



Conclusions

- New Terra ADMs meet CERES TOA flux accuracy requirements.

- Notable improvements in TOA flux accuracy relative to CERES/TRMM ADMs for:
  - Snow and sea-ice (SW and LW)
  - Clear and all-sky land (SW)

- Expect large differences between ES8 and SSF cloud radiative forcing:
  => large increase in SW CRF from SSF (~5 W m^{-2}); modest increase in LW CRF (~2 W m^{-2})

- Differences between ES8 and SSF scene id and ADMs alone do not explain the ~5 W m^{-2} imbalance in global annual net radiation observed in ERBE.

-Instantaneous SW TOA flux accuracy best for low-level overcast conditions (~4%); worst for thin and multi-layer clouds (~10%).

-Greatest challenge for LW TOA flux accuracy for high thin clouds.

-Changes in cloud algorithm and snow map in SSF ED2 induces large SW flux changes relative to ED1, but small LW changes:

-=> Zonal avg SW flux decreases by up to 5 W m^{-2} between 60-70N

=> Zonal average LW flux decreases by up to 0.5 W m^{-2}.

Backup Slides

CERES/Terra ED2 SW ADMs

(Note: ED1 Cloud Algorithm is used for scene ID)

Clear Ocean

Similar approach as for CERES/TRMM but with 2° angular bin resolution. Wind speed dependent empirical ADMs + theoretical correction for aerosol optical depth variations.

* 6 bins of wind speed (0-12 m s^{-1} in steps of 2 m s^{-1})
* 45 solar zenith angle bins (0-90 deg in steps of 2 deg)
* 45 viewing zenith angle bins (0-90 deg in steps of 2 deg)
* 90 relative azimuth angle bins (0-180 deg in steps of 2 deg)

Clouds Over Ocean

Clouds over Ocean:

"Continuous" ADMs using sigmoidal fit approach for 3 cloud phase categories:

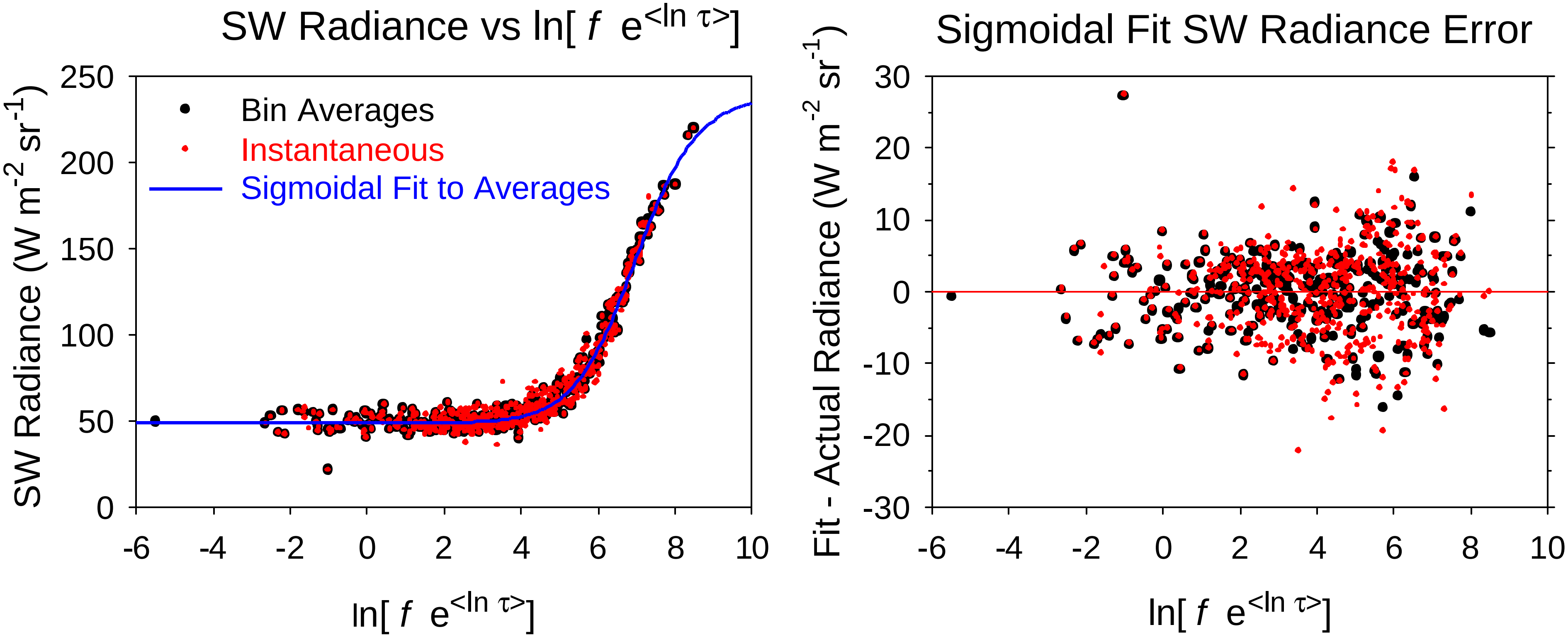
i) Liquid Water (Phase < 1.01)

ii) Mixed Phase ($1.01 \leq$ Phase ≤ 1.75)

iii) Ice (Phase > 1.75)

Uncertainties in Sigmoidal SW Radiance Fits

(Liquid Water Clouds; θ_o=34°-36°; θ=50°-52°; ϕ=6°-8°; TRMM+Terra RAPS+Alongtrack)



Avg Rad = 70.5 W m^{-2} sr^{-1}
Bias = 0.038 W m^{-2} sr^{-1} (0.05%)
Stdev = 5.26 W m^{-2} sr^{-1} (7.5%)

Five Parameter Sigmoid

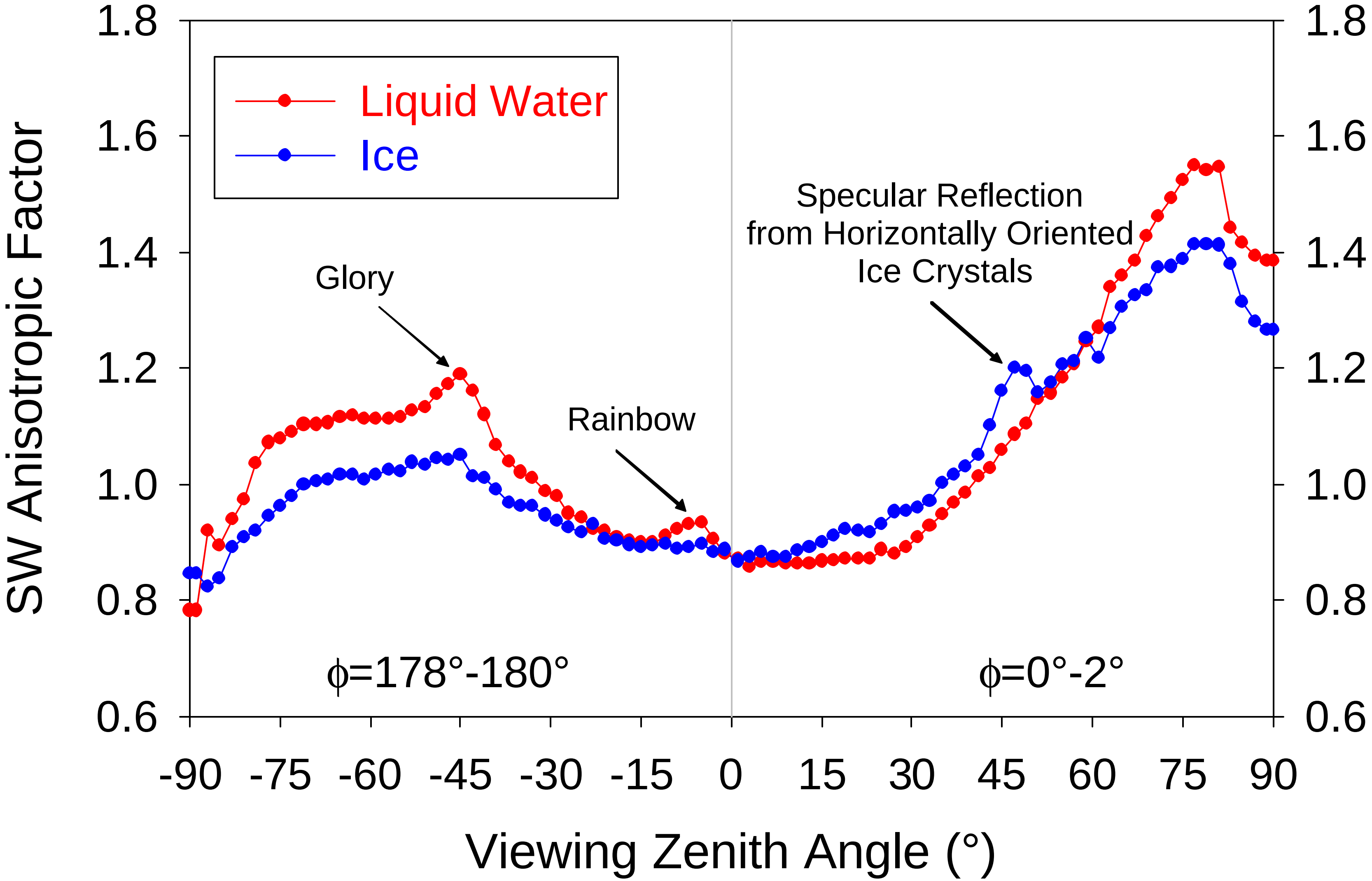
$$I = I_o + \frac{a}{\left[1+e^{-\left(\frac{x-x_o}{b}\right)}\right]^c}$$

where, $x = \ln(f \times e^{<\ln t>})$

$x_o, I_o, a, b, c =$ coefficients of fit

CERES/Terra ADM Anisotropic Factors in the Principal Plane

(θ_o=44°-46°; Ocean; f $e^{<\ln\tau>}$ = 7.5; November 2000 - August 2001)



Glint Avoidance

In sunglint, radiance-to-flux conversion is highly uncertain both for clear and cloudy conditions.

Clear Scenes:

To determine whether or not to perform a radiance-to-flux conversion, the standard deviation (σ_{clr}) of the clear ocean ADM anisotropic factors in the vicinity of the measurement (i.e. surrounding w_s, θ_o, θ, and ϕ bins) must be less than 0.05.

Otherwise, use ADM mean flux corresponding to ADM scene type.

Cloudy Scenes:

Perform radiance-to-flux conversion if: $(1-f_{cld})\ \sigma_{clr} < 0.05$

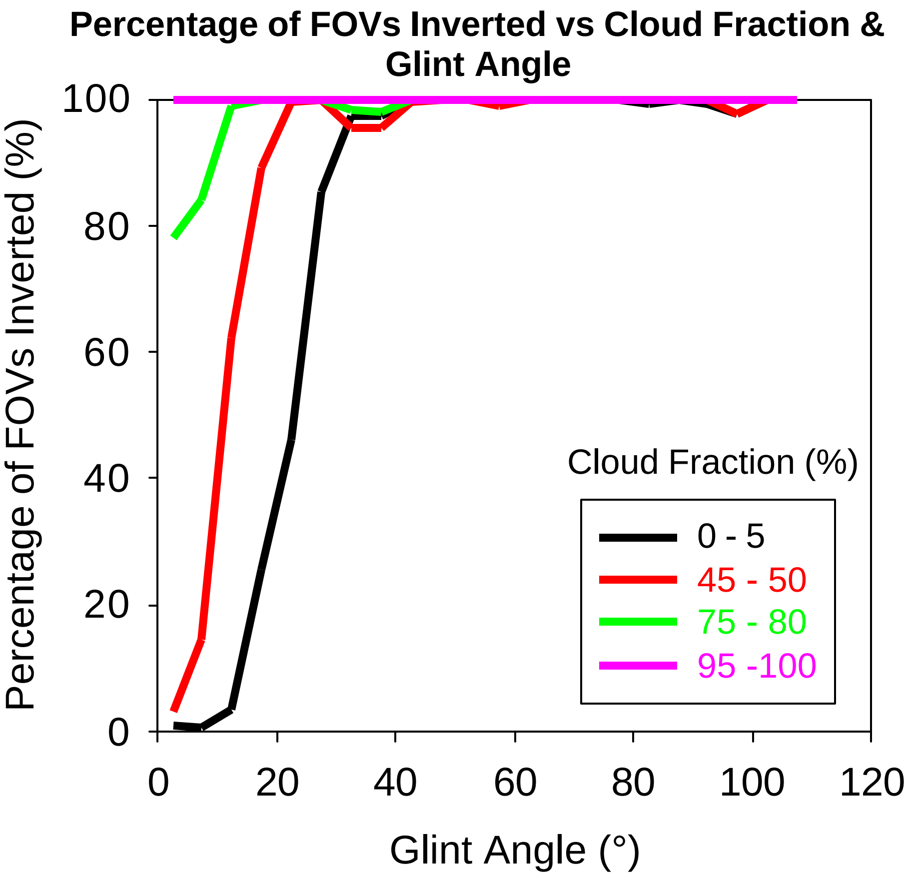
Otherwise, use ADM mean flux corresponding to cloudy ADM scene type.

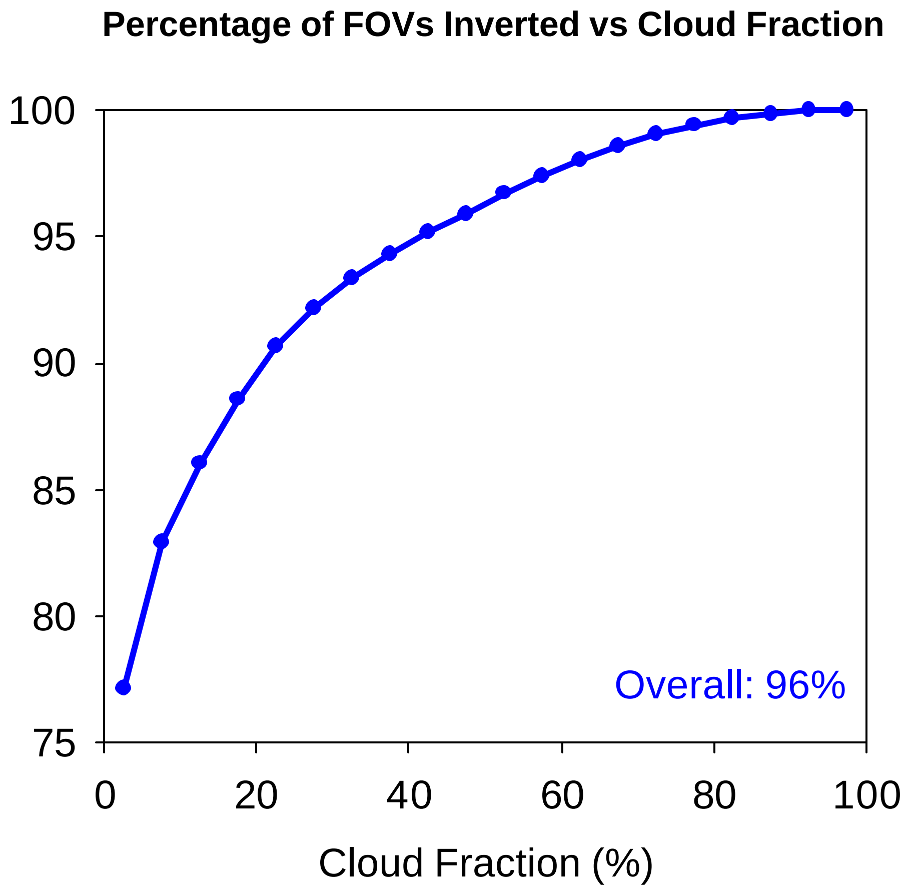
Sea Ice:

Perform radiance-to-flux conversion if: $(1-f_{ice})(1-f_{cld})\ \sigma_{clr} < 0.05$

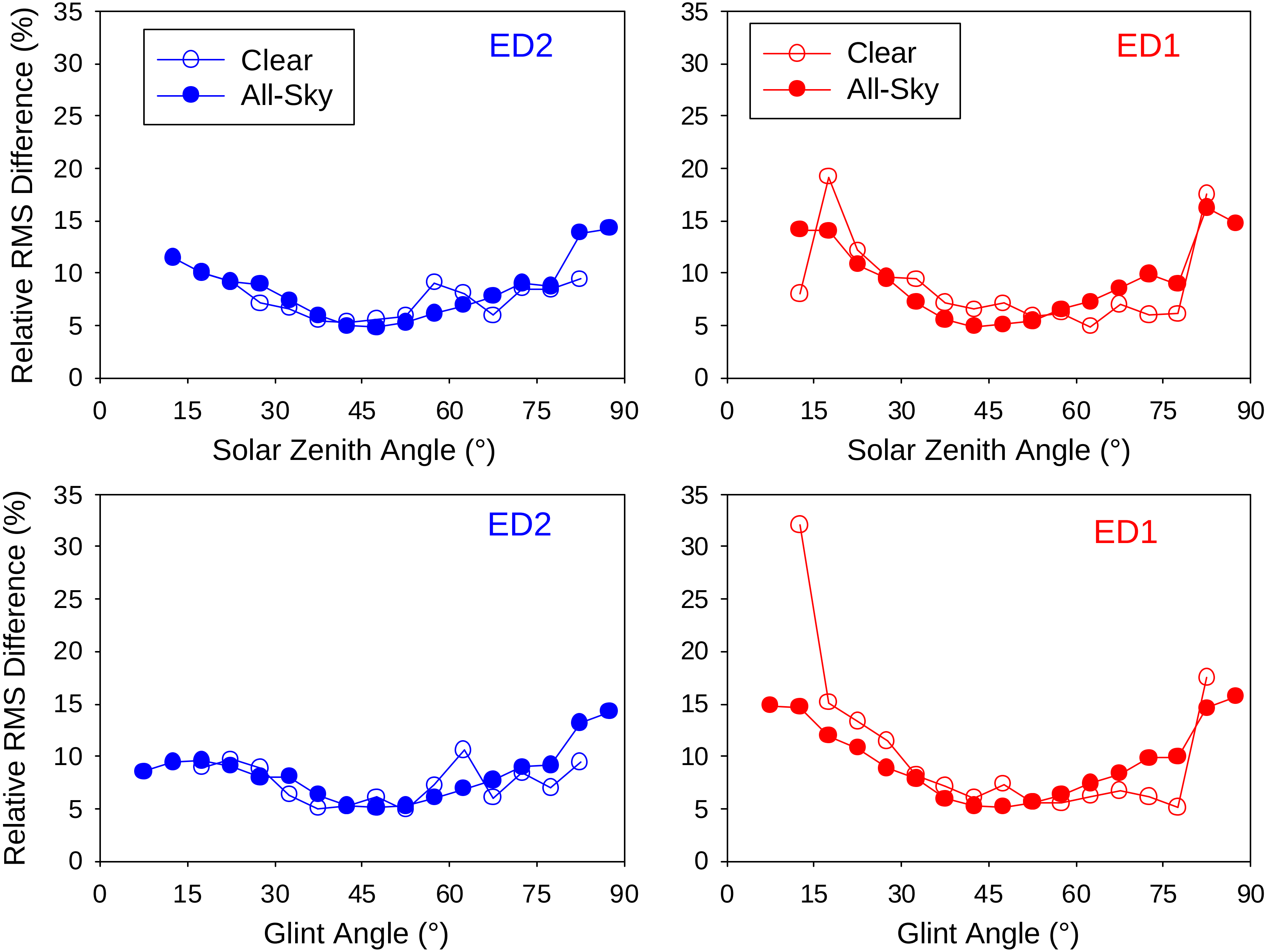
Otherwise, use ADM mean flux corresponding to sea-ice ADM scene type.

Percentage of CERES FOVs Passing Sunglint Avoidance Test
(December, 2001; Crosstrack)





Instantaneous TOA Flux Consistency by Solar Zenith Angle and Glint Angle
(Ocean Only)



Clear Land & Desert

- Collect one month of clear land CERES reflectances over ≈1° equal-area regions. Stratify by solar zenith angle and TOA NDVI.
- If sampling over angle is sufficient, use an 8-parameter nonparametric fit (from Ahmad and Deering, 1992) to produce brdf and ADM for the ≈1° region.

$$r(m, f; m_o) = \frac{1}{4}\frac{w}{m+m_o}\left\{1-\exp\left[-t\left(\frac{1}{m}+\frac{1}{m_o}\right)\right]\right\}\cdot\left\{P(a)\left[1+B(a')\right]\right\}+\frac{1}{4}\frac{w}{m+m_o}$$

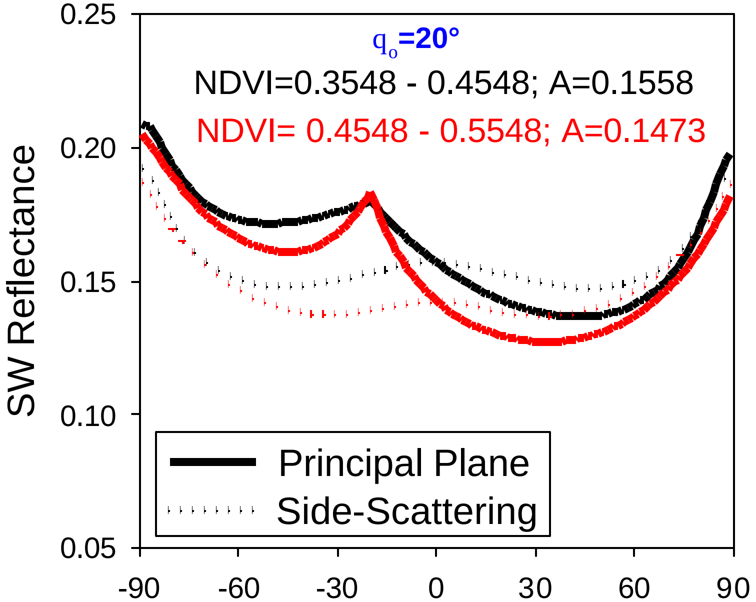
$$\cdot\left[H^{(0)}(m)H^{(0)}(m_o)(1-e(m+m_o)-b(1-w)mm_o+b(1-m^2)^{1/2}\cdot(1-m_o^2)^{1/2}H^{(1)}(m)H^{(1)}(m_o)\cos f\right]$$

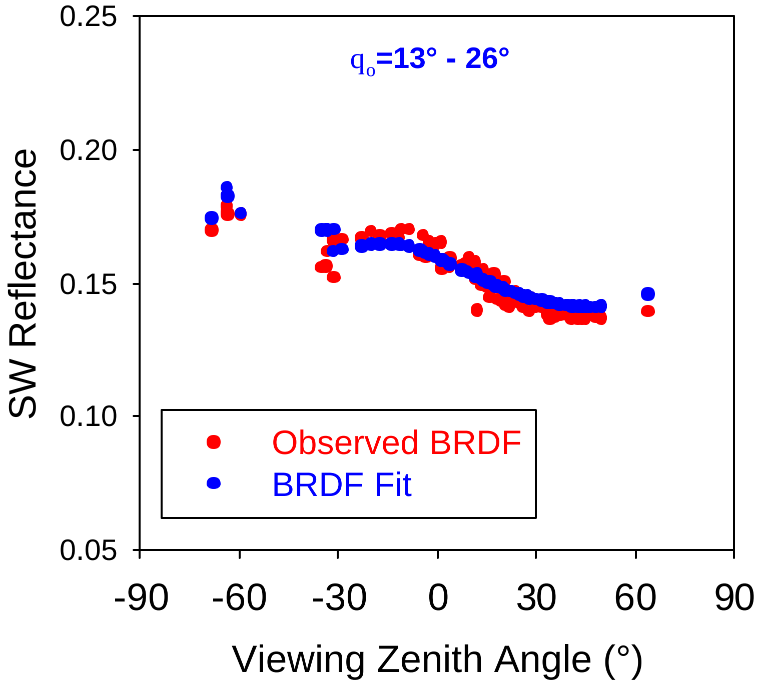
$$-\frac{1}{4}\frac{w}{m+m_o}P'(a)+\left(d_o+\frac{d_1}{m+m_o}\right)$$

-Multiple scattering based on Chandrasekhar’s RT solution for semi-infinite medium.

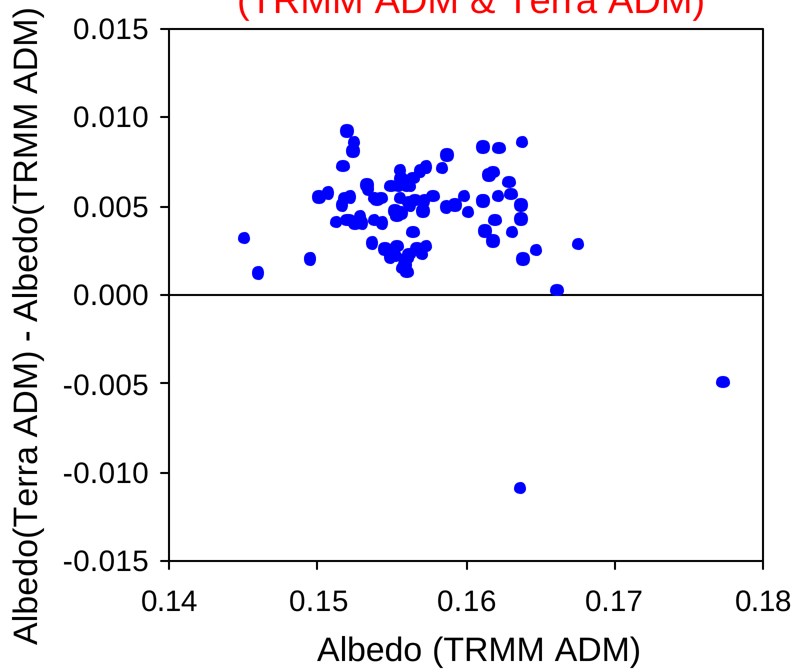
-“Hot-spot” modeled using empirical term (Hapke, 1986).

BRDF in Vicinity of SGP ARM Site (June, 2000)

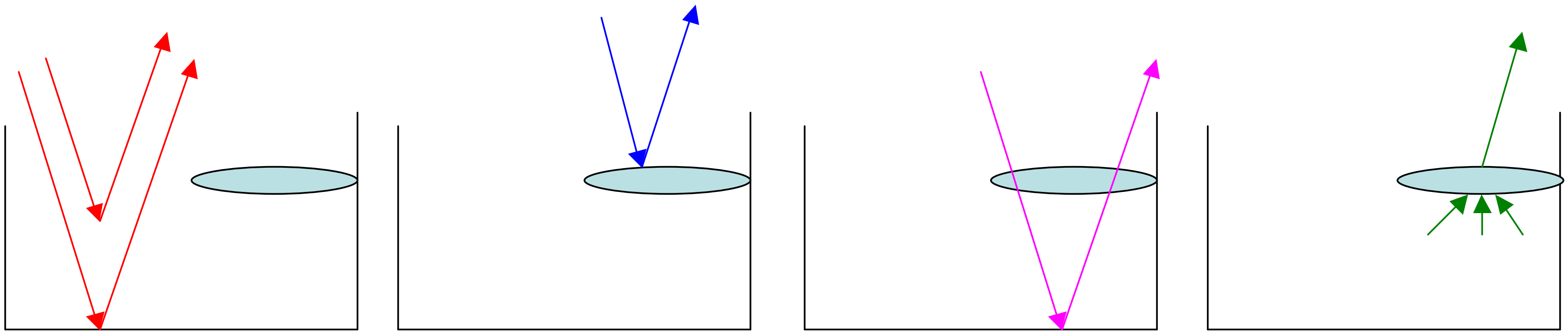




Instantaneous Albedos
(TRMM ADM & Terra ADM)



Clouds Over Land & Desert



i) Solve for $f\ I^{cld}(m_o, m, f)$ from:

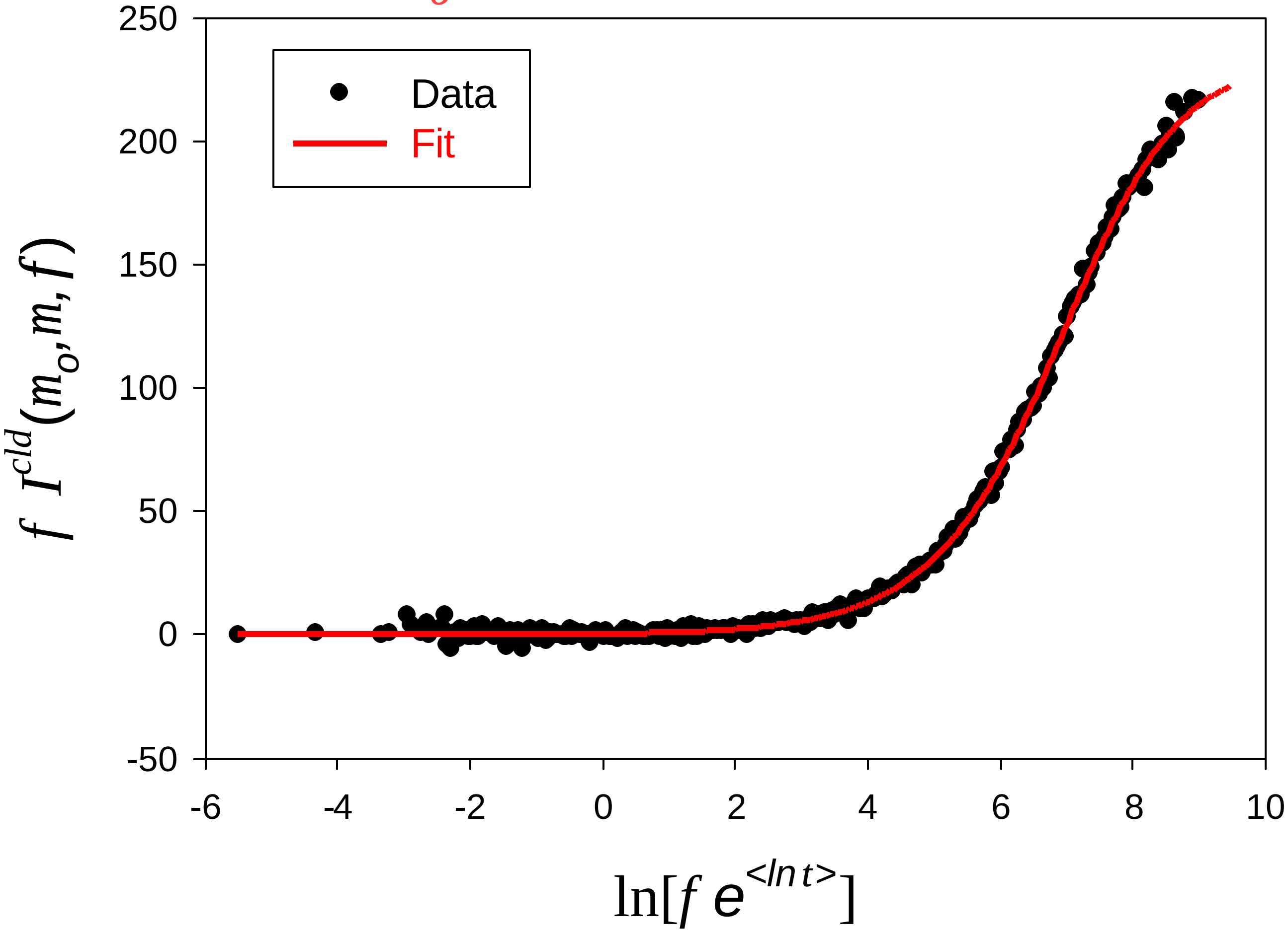
$$I^{obs}(m_o, m, f) = (1 - f)\frac{m_o E_o}{p} r^{clr}(m_o, m, f) + f\ I^{cld}(m_o, m, f) +$$

$$f\left[\frac{m_o E_o}{p} r^{clr}(m_o, m, f) e^{-\frac{t}{m_o}} e^{-\frac{t}{m}} + \frac{E_o a^{clr}}{p}\left(\frac{T^{cld}(t, m_o) T^{cld}(t, m)}{1 - a^{clr} - a^{cld}(t)}\right)\right]$$

ii) Determine fits for $f\, I^{cld}(m_o, m, f)$ *vs* $ln(f\, e^{<ln\, t>})$ (independent of surface type):

Sigmoidal Fit Over Land

(q_o = 40°-45°; q = 0°-5°)



iii) Instantaneous TOA flux inferred from:

$$\hat{F} = \frac{\pi I^{obs}(\mu_o,\mu,\phi)}{\hat{R}}$$

$$\hat{R} = \frac{\pi \hat{I}(\mu_o,\mu,\phi)}{\int_0^{2\pi}\int_0^1 \hat{I}(\mu_o,\mu,\phi)\mu \, d\mu \, d\phi}$$

Predicted from sigmoidal fit

$$\hat{I}(\mu_o,\mu,\phi) = (1-f)\frac{\mu_o E_o}{\pi}\rho^{clr}(\mu_o,\mu,\phi) + f\, I^{cld}(\mu_o,\mu,\phi) +$$

$$f\left[\frac{\mu_o E_o}{\pi}\rho^{clr}(\mu_o,\mu,\phi)e^{-\frac{\tau}{\mu_o}}e^{-\frac{\tau}{\mu}} + \frac{E_o\alpha^{clr}}{\pi}\left(\frac{T^{cld}(\tau,\mu_o)T^{cld}(\tau,\mu)}{1-\alpha^{clr}-\alpha^{cld}(\tau)}\right)\right]$$

Definition of Snow and Ice

- Permanent Snow

  Dominant surface type is permanent snow

- Fresh Snow

  Dominant surface type is fresh snow or

  Imager detects snow/ice over land and surface

  temperature is less than 280 K.

- Sea Ice

  Dominant surface type is fresh snow or

  Imager detects snow/ice over ocean and sea surface temperature is less than 280 K.

Bright and Dark Snow/Ice

- Bright or Dark snow is determined based on a snow map made from nadir view (? < 25) MODIS 630 nm radiances.
- The snow map is made by:

  1) Determine mean reflectance as a function of snow type and solar zenith angle.

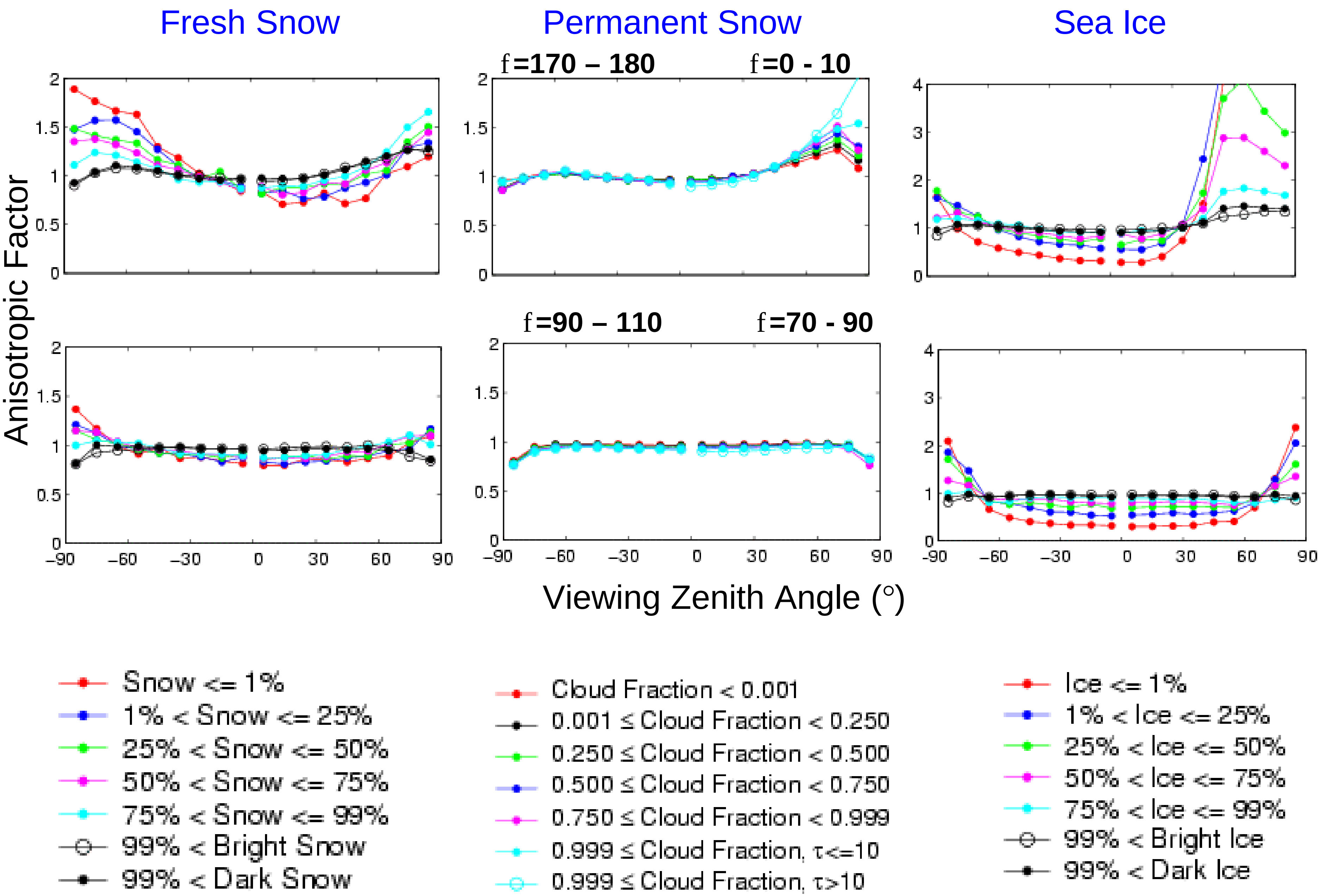
  2) Every nadir view reflectance is classified as bright (1) or dark (-1).

  3) If the sum of all classification from one month of data in a 1 degree by 1 degree is positive, the area is classified as bright snow.

Snow and Ice ADM Scene Type Classifications

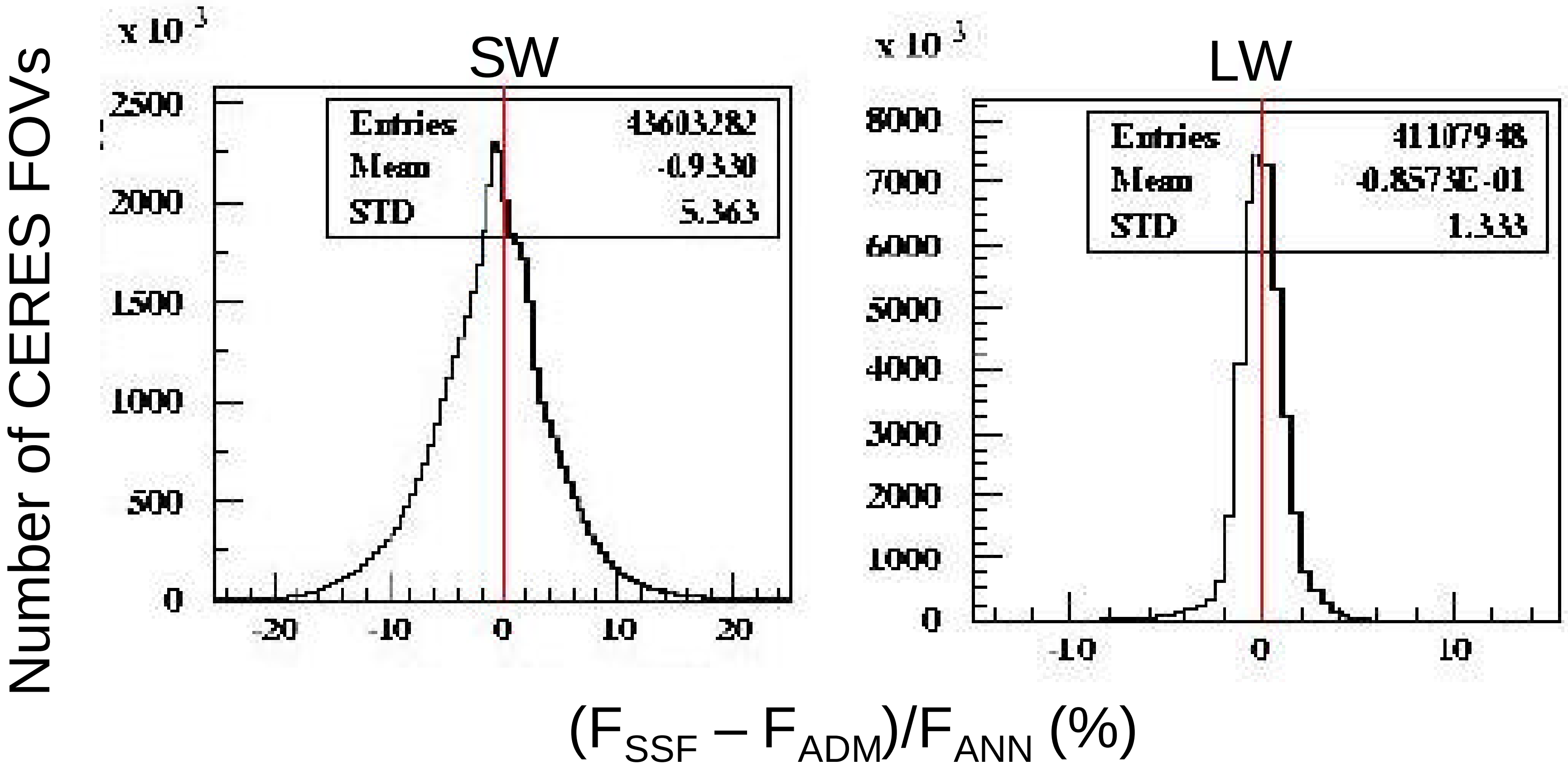
	Shortwave	Longwave
Permanent Snow SW (10) LW (24)	Cloud Fraction (6) Snow (2), Cloud (2)	Cloud Fraction (6) Tsfc (2) Tsfc-Tcld(2)
Fresh Snow SW (22) LW (24)	Cloud Fraction (6) Snow Fraction (6) Snow (2), Cloud (2)	Cloud Fraction (6) Tsfc (2) Tsfc-Tcld (2)
Sea Ice SW (22) LW (24)	Cloud Fraction (6) Ice Fraction (6) Ice (2), Cloud (2)	Cloud Fraction (6) Tsfc (2) Tsfc-Tcld (2)

Sample SW ADMs: θ_o=55° - 60°



Use of Neural Network Scheme to Predict TOA Fluxes

- Determine TOA fluxes when imager information is unavailable or too many pixels have no cloud retrieval.
- Train neural network with TRMM ADMs to predict TOA fluxes using only CERES SW, LW & WN radiances and ECMWF parameters.

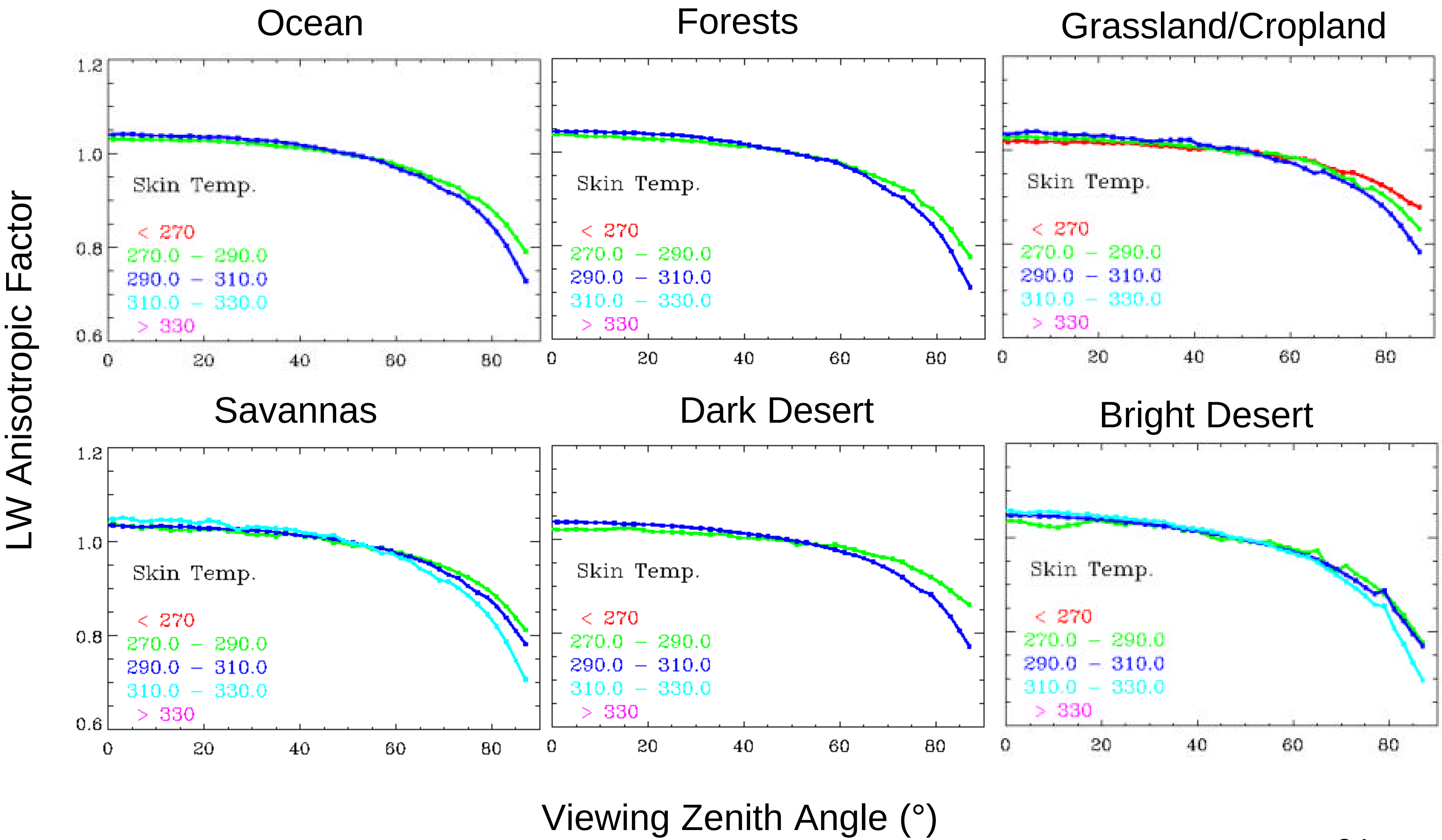


CERES/Terra ED2 LW ADMs

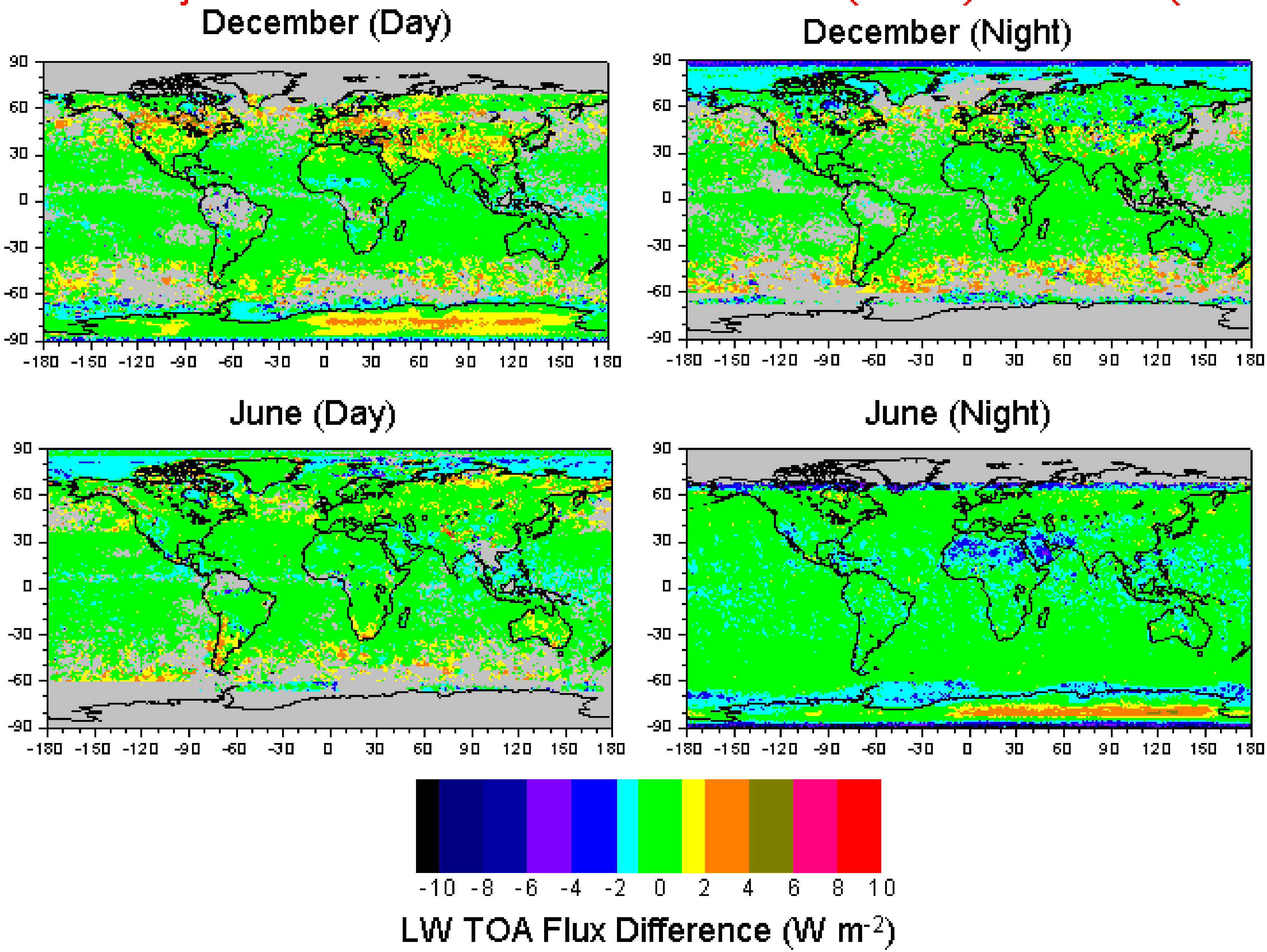
Longwave and Window ADM Scene Types for Clear Scenes

Scene Type Parameters	TRMM	Terra
Surface Type	Ocean Land Desert	Ocean Forest, Cropland/Grass, Savanna, Bright Desert, Dark Desert
Precipitable Water	Intervals (Percentile) ≤ 33 33 – 66 ≥ 66	Intervals (cm) ≤ 1 1 - 3 3 - 5 > 5
Vertical Temperature Change	Intervals (Percentiles) Inversion ($\Delta T < 0$) 0-25 25-50 50-75 > 75	Intervals (°C) < 15 15 – 30 30 – 45 > 45
Skin Temperature		Intervals (K) < 270 270 – 290 290 – 310 310 – 330 > 330

Sample Clear-Sky LW ADMs
(w=0-1 cm; Vert. Temp. Diff.= 15-30°C)



Clear-Sky LW TOA Flux Difference: Terra(ADM) – TRMM(ADM)



Terra LW & WN ADMs: Cloudy Scenes

- For scene types stratified by:
  - i) surface type (ocean, land, desert)
  - ii) precipitable water (4 intervals)
  - iii) skin temperature (11 intervals)
  - iv) surface-cloud temperature difference (22 intervals)

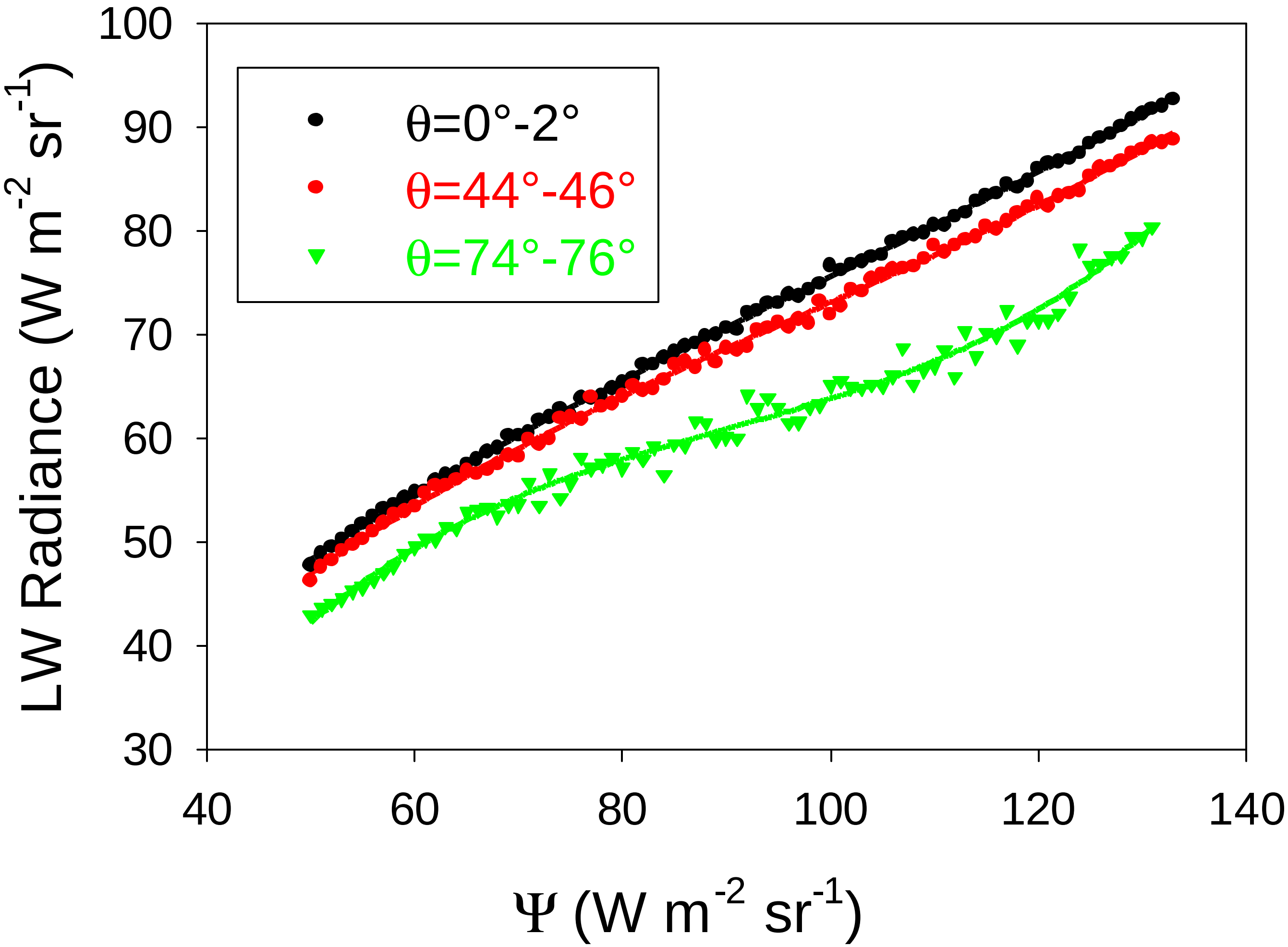
Derive functional fits in 2° viewing zenith angle increments between CERES LW (WN) radiance and the parameter ψ defined by:

$$y\,(\Delta w, \Delta z_t; f, e_s, T_s, e_c, T_c) = (1 - f) e_s B(T_s) + \sum_{j=1}^{2} \Big(e_s B(T_s)[1 - e_{c_j}(q)] + e_{c_j}(q) B(T_{c_j}) \Big) f_j$$

$$e_c(q) = 1 - e^{t_a/\cos q}; \quad f = f_1 + f_2$$

LW Radiance vs Ψ

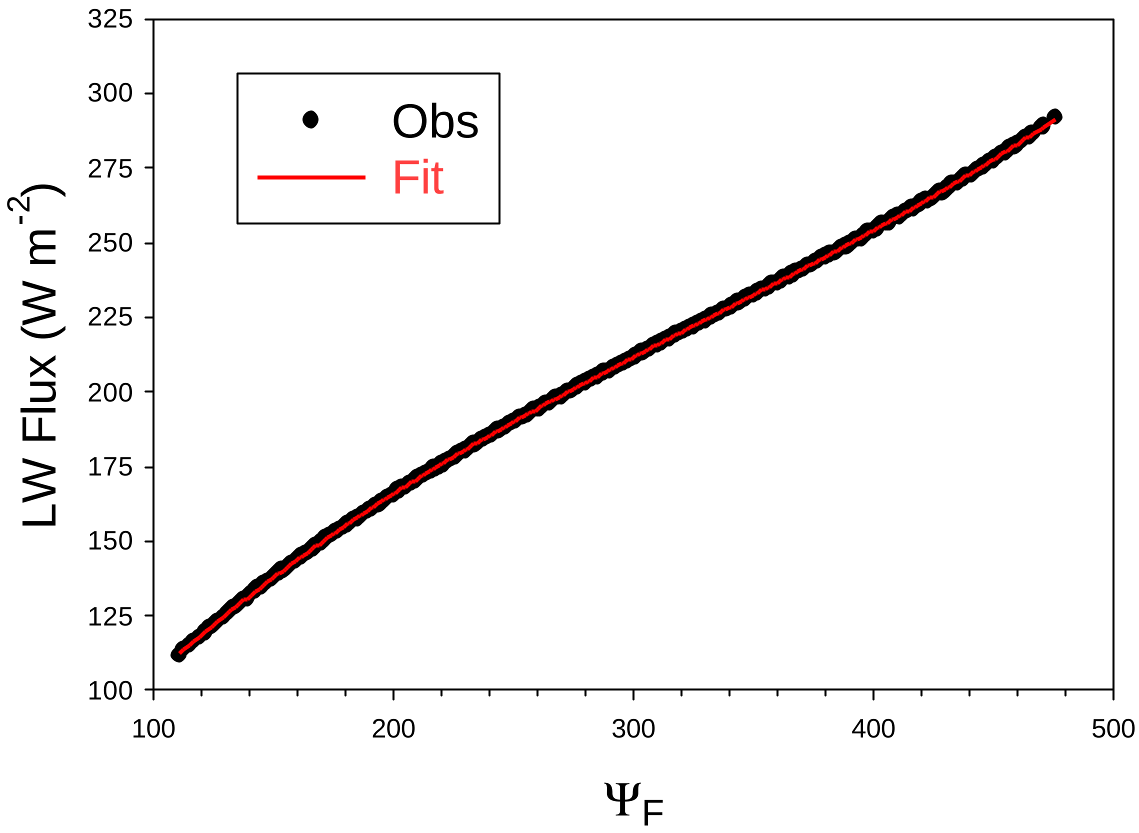
(290°K < T_s < 295°K; 55°K < T_s-T_c < 60°K)



$$y\,(\Delta w, \Delta z_t; f, e_s, T_s, e_c, T_c) = (1-f)e_s B(T_s) + \sum_{j=1}^{-}\left(e_s B(T_s)(1-e_{c_j}) + e_{c_j} B(T_{c_j})\right) f_j$$

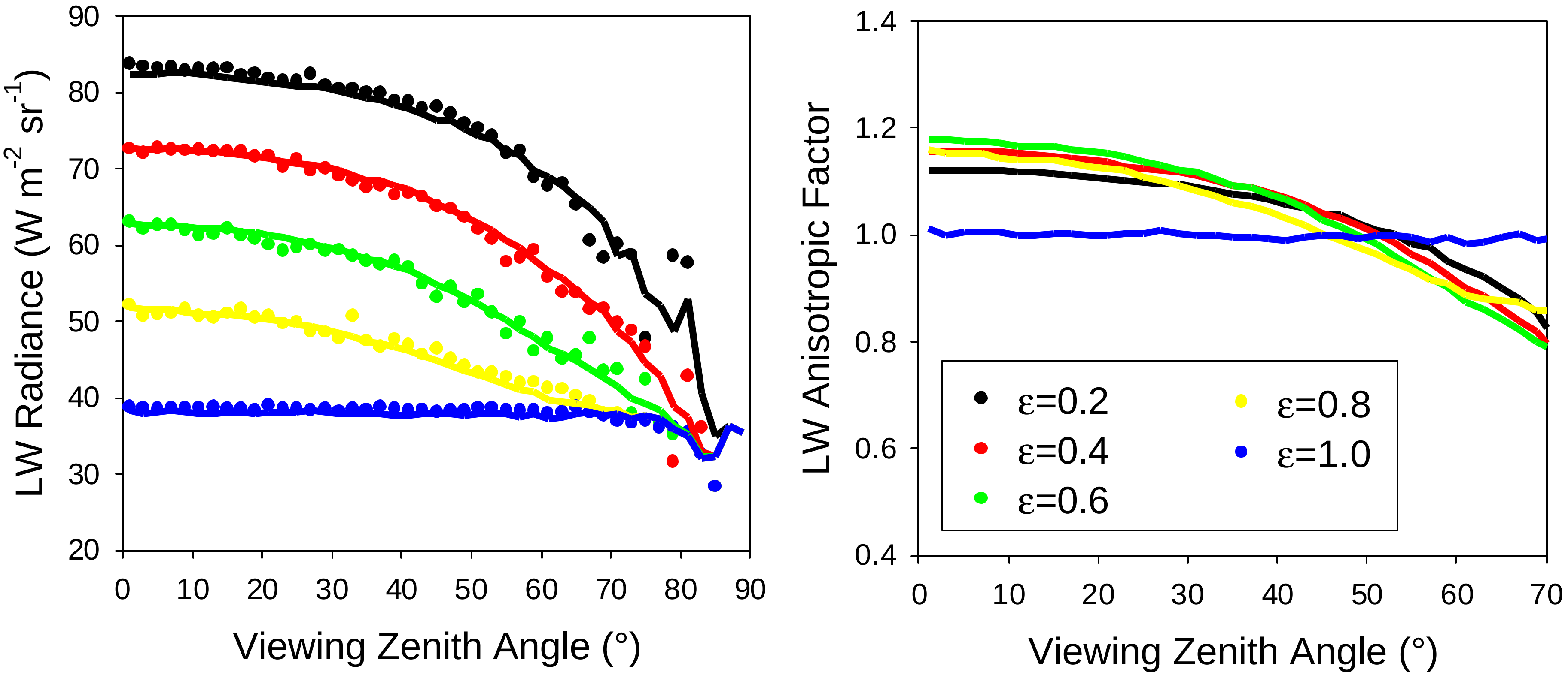
LW Flux vs Ψ_F

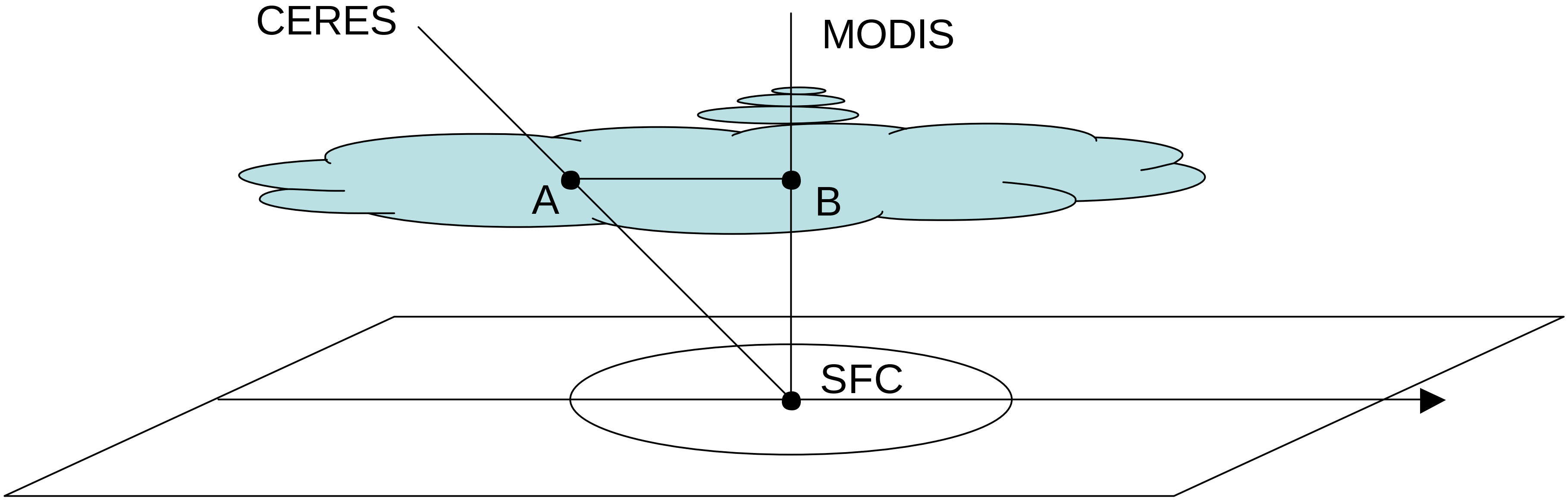
(Ocean; w=4 cm^{-1}; T_s=300 K; Ts-Tc=85 K)



$$\Psi_F = 2\pi \int_0^1 \Psi(\mu)\mu d\mu$$

LW Radiance & Anisotropy: Clouds Over Ocean
(w=4 cm^{-1}; Ts=300 K; Ts-Tc=85 K)





MODIS pixels within a CERES FOV are identified using a surface reference level.

⇒ This is appropriate for clear scenes, but not for clouds since CERES and MODIS "see" different parts of a cloud (A and B above).

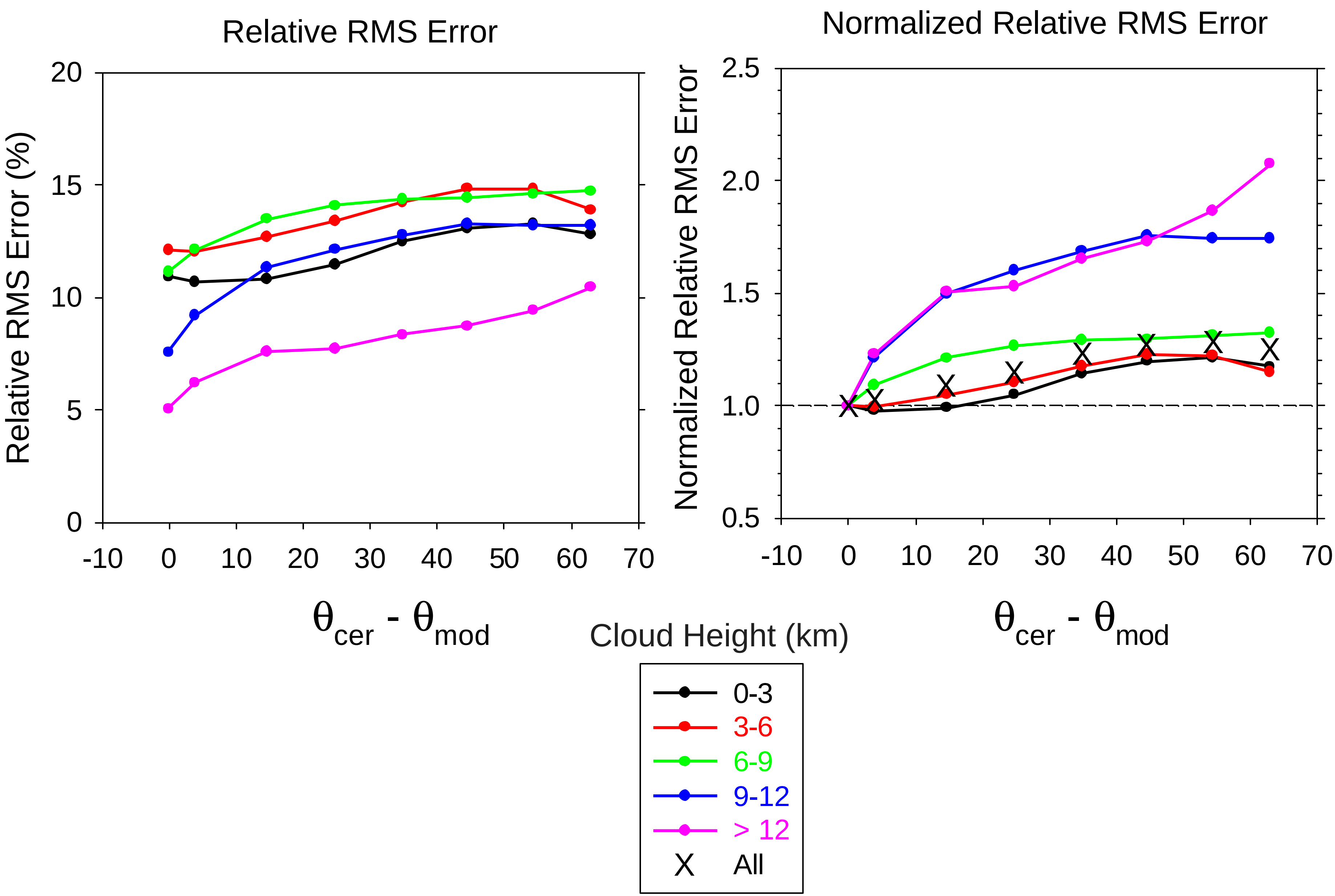
CERES-MODIS flux difference due to inappropriate reference level increases with:

(i) Cloud height.

(ii) Difference between CERES and MODIS viewing angles.

(iii) Cloud inhomogeneity.

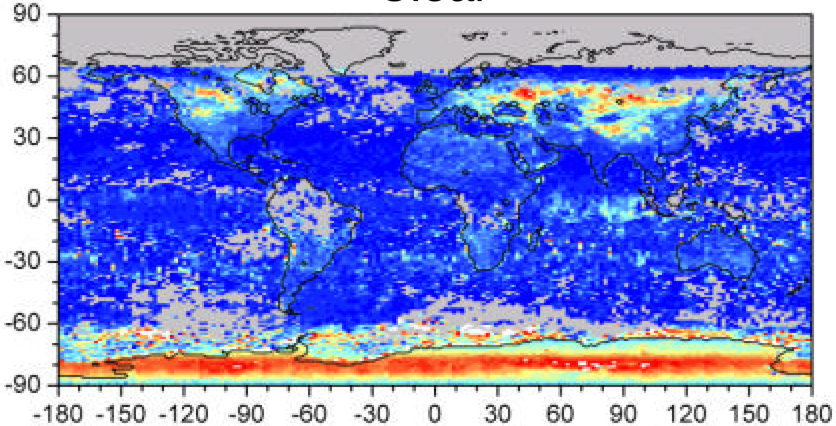
Error in ADM-Estimated SW Radiance for q_{cer} > 50°
(RAP, Sep-Oct 2001, Sep-Oct 2002; Tropics)



ED1 – ED2 SW TOA Flux RMS Difference

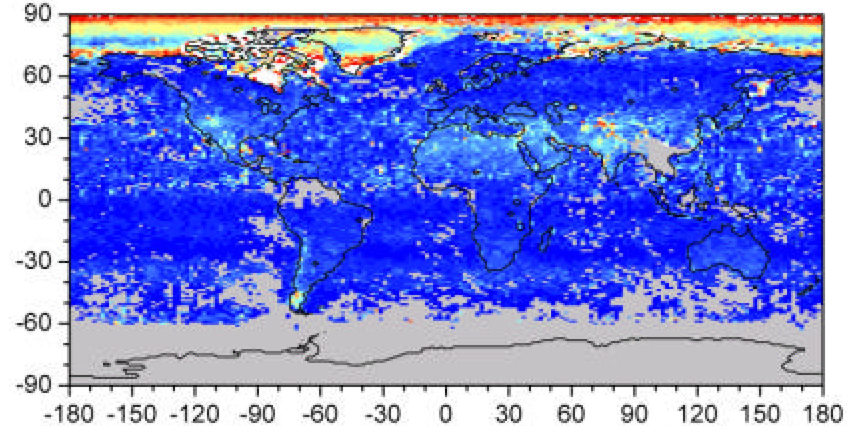
December, 2001

Clear

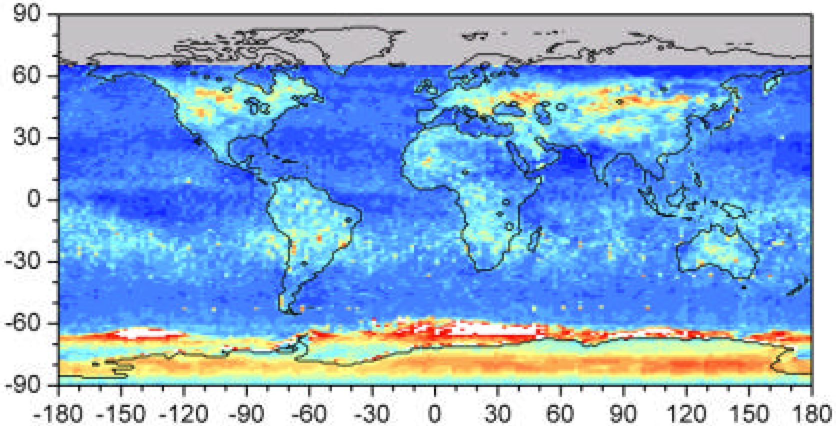


June, 2002

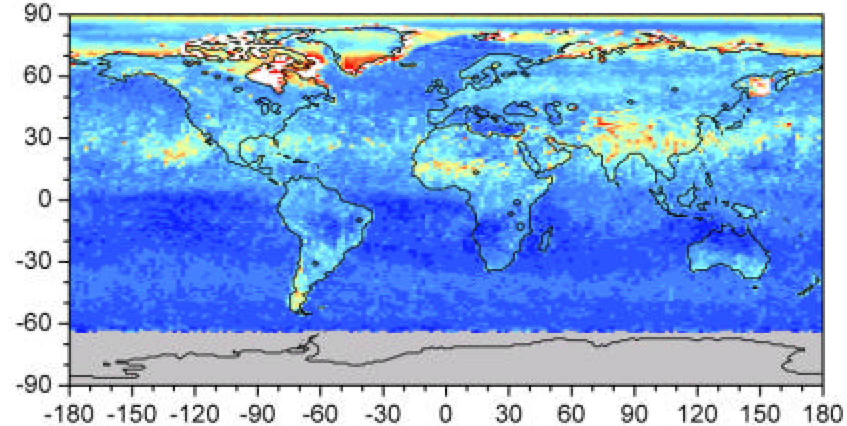
Clear

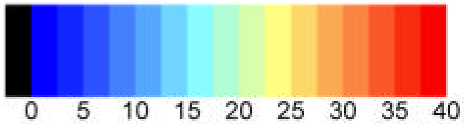


All-Sky

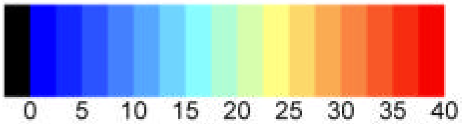


All-Sky





RMS Difference (W m^{-2})



RMS Difference (W m^{-2})

ED1 – ED2 LW TOA Flux RMS Difference