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, W. Sun, W.F. Miller

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Outline

1. CERES/Terra ADMs – Brief Overview.

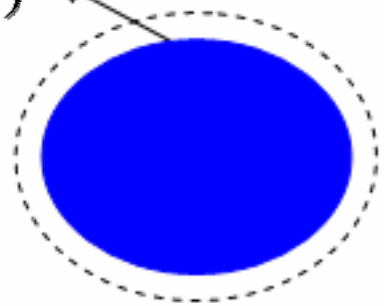
2. TOA Flux Uncertainties: monthly mean, instantaneous.

3. Comparisons between CERES SSF and ERBE-Like fluxes.

Instantaneous Fluxes at TOA and Angular Distribution Models

CERES Radiance Measurement

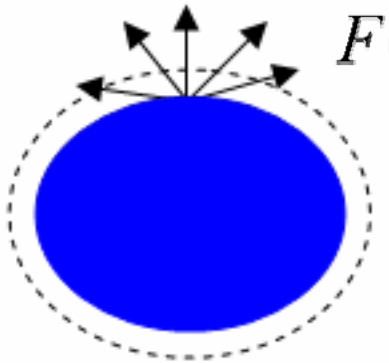
$L(\theta_o, \theta, \phi)$



$\Rightarrow$

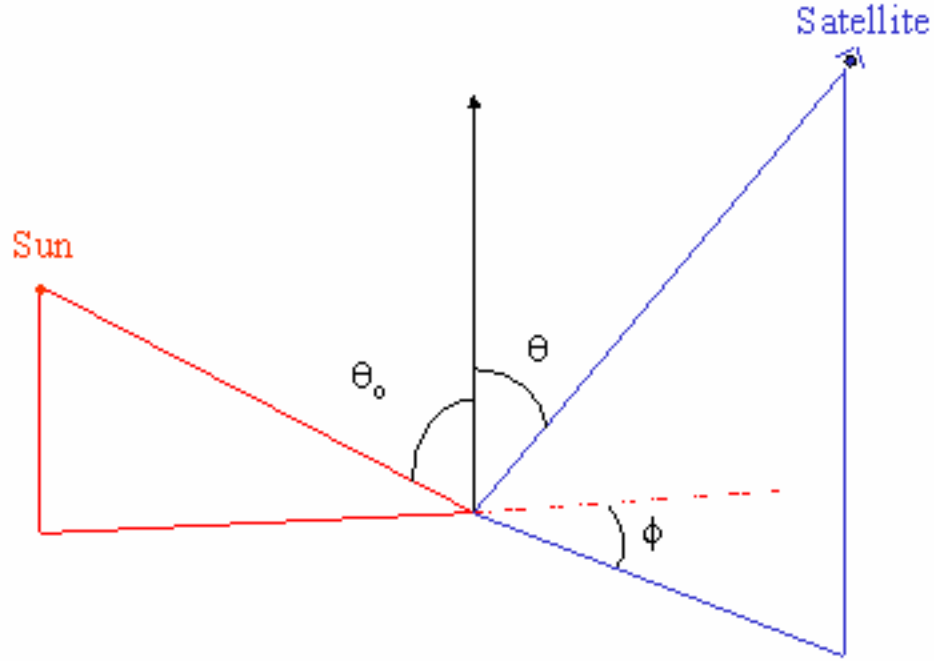
TOA Flux Estimate

$F(\theta_o)$



SW
LW
WN

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



TOA flux estimate from CERES radiance:

$$\hat{F}(\theta_o,\theta,\phi) = \frac{\pi L(\theta_o,\theta,\phi)}{R_j(\theta_o,\theta,\phi)}$$

where,

$$R_j(\theta_o,\theta,\phi) = \frac{\pi L_j(\theta_o,\theta,\phi)}{\int_0^{2\pi}\int_0^{\frac{\pi}{2}} L_j(\theta_o,\theta,\phi)\cos\theta\ \sin\theta\ d\theta d\phi}$$

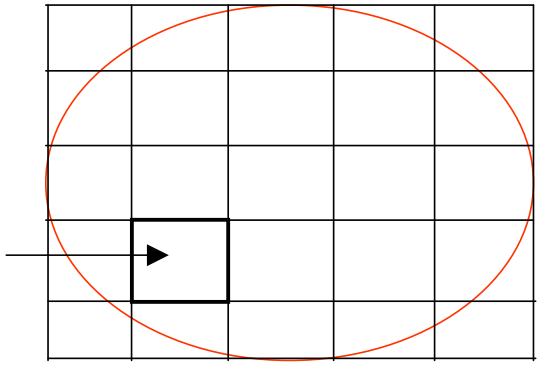
$R_j(\theta_o,\theta,\phi)$ is the Angular Distribution Model (ADM) for the "jth" scene type.

CERES Single Scanner Footprint (SSF) Product

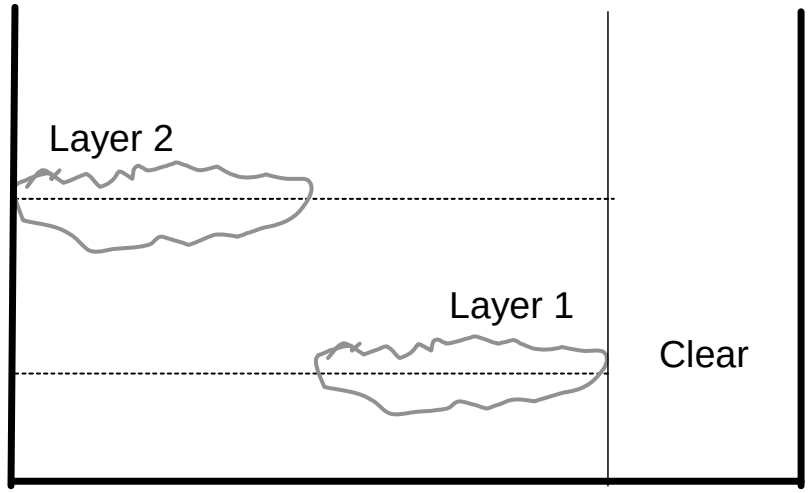
- Coincident CERES radiances and imager-based cloud and aerosol properties (including MOD04 and NOAA-NESDIS aerosol products).
- Use VIRS (TRMM) or MODIS (Terra, Aqua) to determine the following parameters in up to 2 cloud layers over every CERES FOV:

Macrophysical: Fractional coverage, Height, Radiating Temperature, Pressure
Microphysical : Phase, Optical Depth, Particle Size, Water Path
Clear Area : Skin Temperature, Aerosol optical depth, Emissivity

VIRS/MODIS Imager Pixel



CERES Footprint



CERES Footprint

CERES/Terra Shortwave ADMs for Different Scene Types

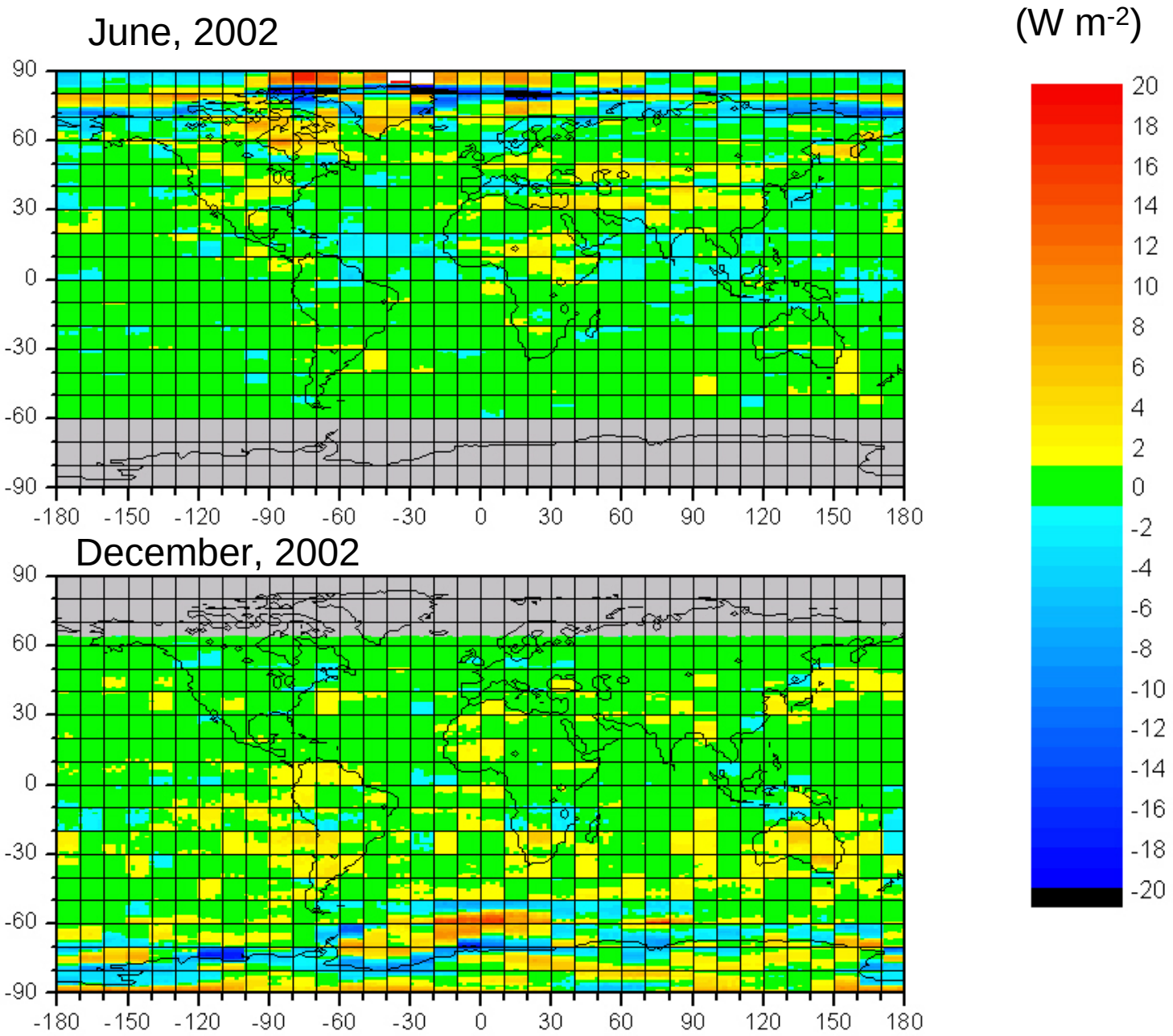
Scene Type	Description
Clear Ocean	Function of wind speed; Correction for aerosol optical depth included.
Cloud Ocean	Function of cloud phase; Continuous function of cloud fraction and cloud optical depth (5-parameter sigmoid).
Land & Desert Clear	1° regional monthly ADMs using Analytical Function of TOA BRDF (Ahmad and Deering, 1992).
Land & Desert Cloud	Function of cloud phase; continuous function of cloud cover and cloud optical depth; uses 1°-regional clear-sky BRDFs to account for background albedo.
Permanent Snow	Cloud Fraction, Surface Brightness, cloud optical depth
Fresh Snow	Cloud Fraction, Surface Brightness, Snow Fraction, cloud optical depth
Sea-Ice	Cloud Fraction, Surface Brightness, Ice Fraction, cloud optical depth

CERES/Terra Longwave & Window ADMs for Different Scene Types

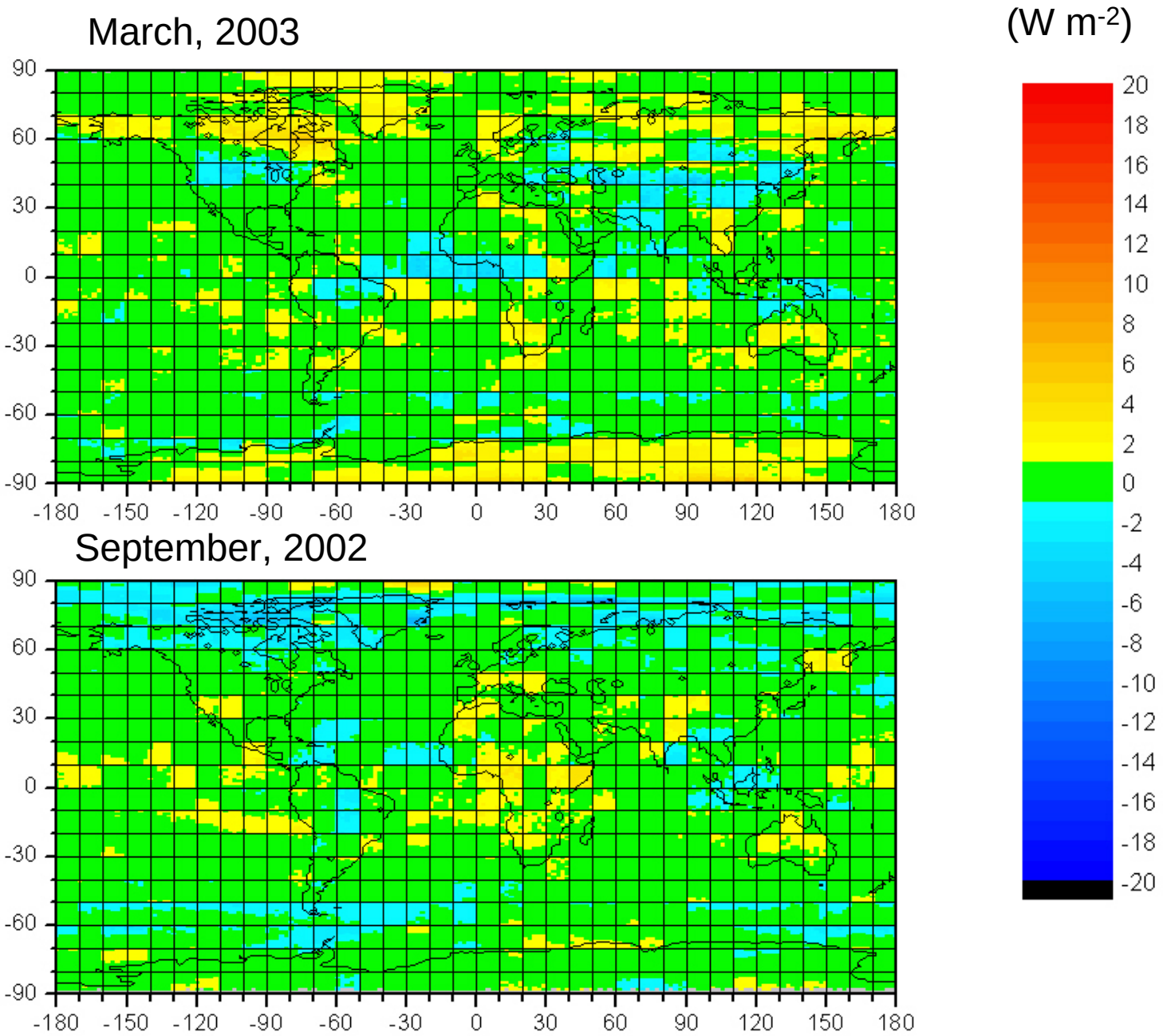
Scene Type	Description
Clear Ocean, Land, Desert	Ocean, Forest, Cropland/Grass, Savanna, Bright Desert, Dark Desert, precip. water, lapse rate, skin temperature
Clouds Over Ocean, Land, Desert	Function of precip. water, skin temp., sfc-cloud temp. diff; continuous function of parameterization involving cloud fraction, cloud and sfc emissivity, sfc and cloud temp.
Permanent Snow Fresh Snow Sea-Ice	Each a function of cloud fraction, sfc temp, sfc-cld temp diff

Uncertainty in Regional Mean TOA Flux due to ADMs

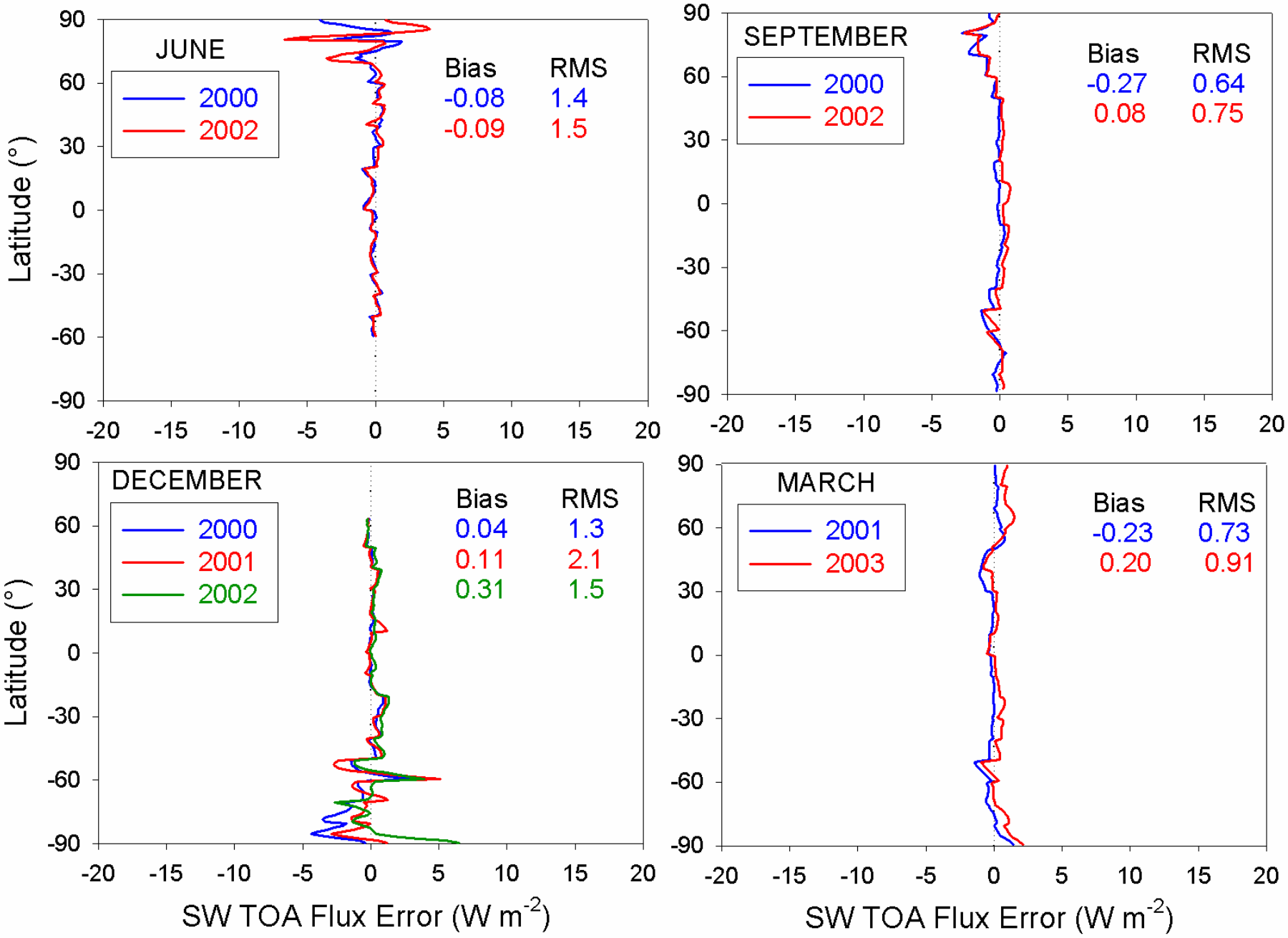
Direct Integration Test: SSF SW TOA Flux Error (24-h Avg)



Direct Integration Test: SSF SW TOA Flux Error (24-h Avg)



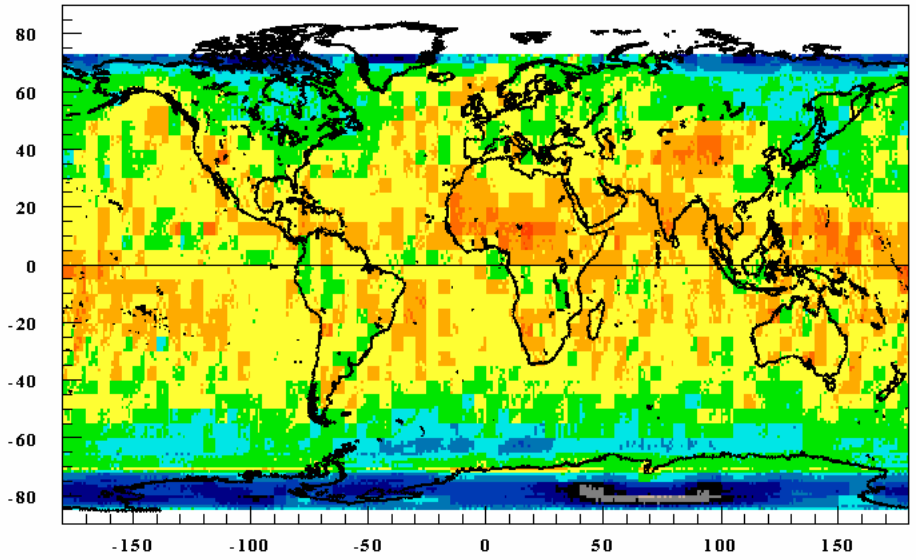
SW TOA Flux Direct Integration Tests (24-h Flux Differences)



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

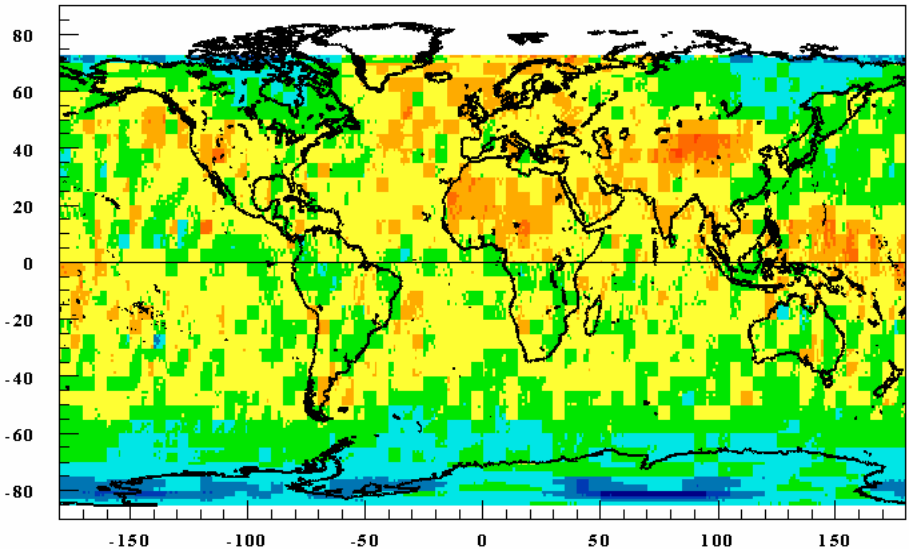
TRMM ADMs
F(ADM) – F(DI)

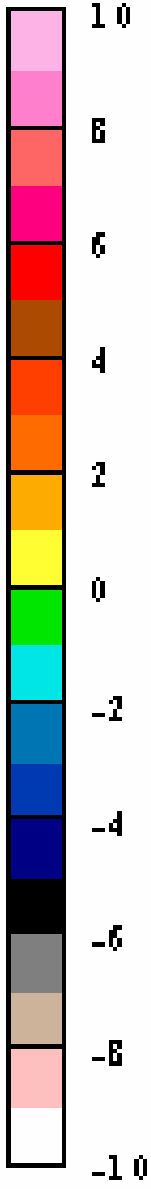
MN DIFF
-0.13 W m^{-2}
RMS Diff
1.45 W m^{-2}



Terra ADMs
F(ADM) – F(DI)

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

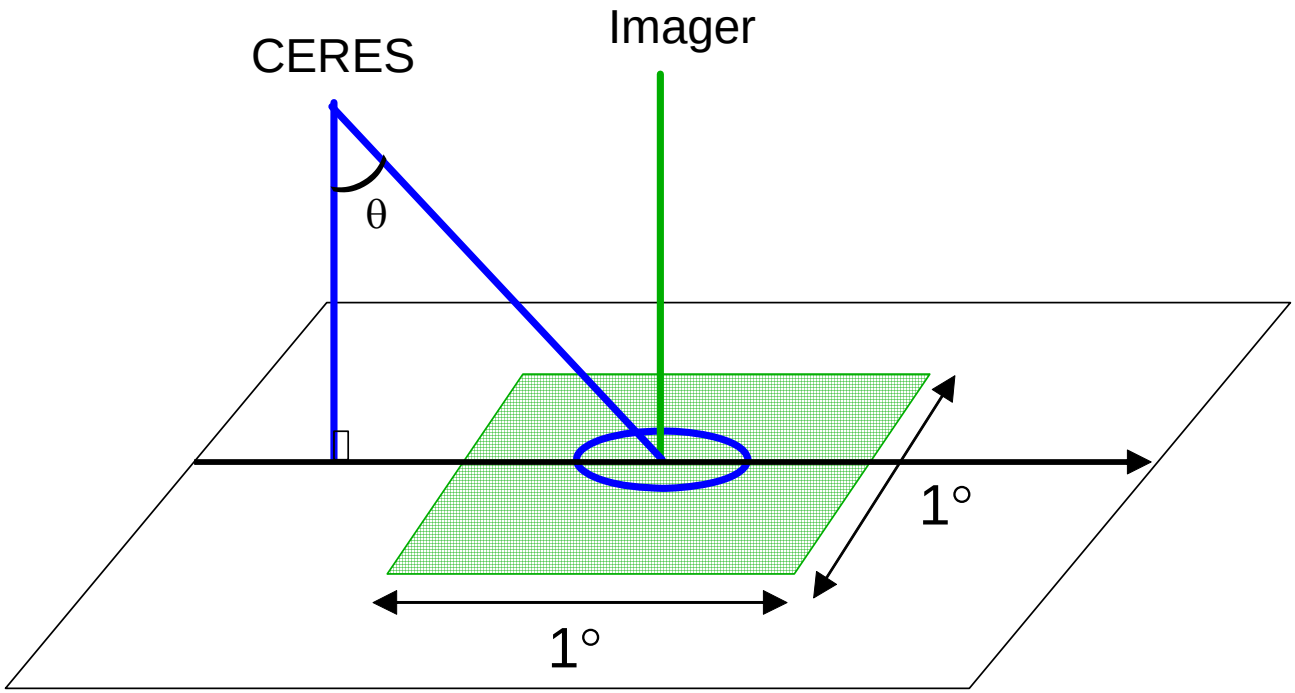




Flux Error
(W m^{-2})

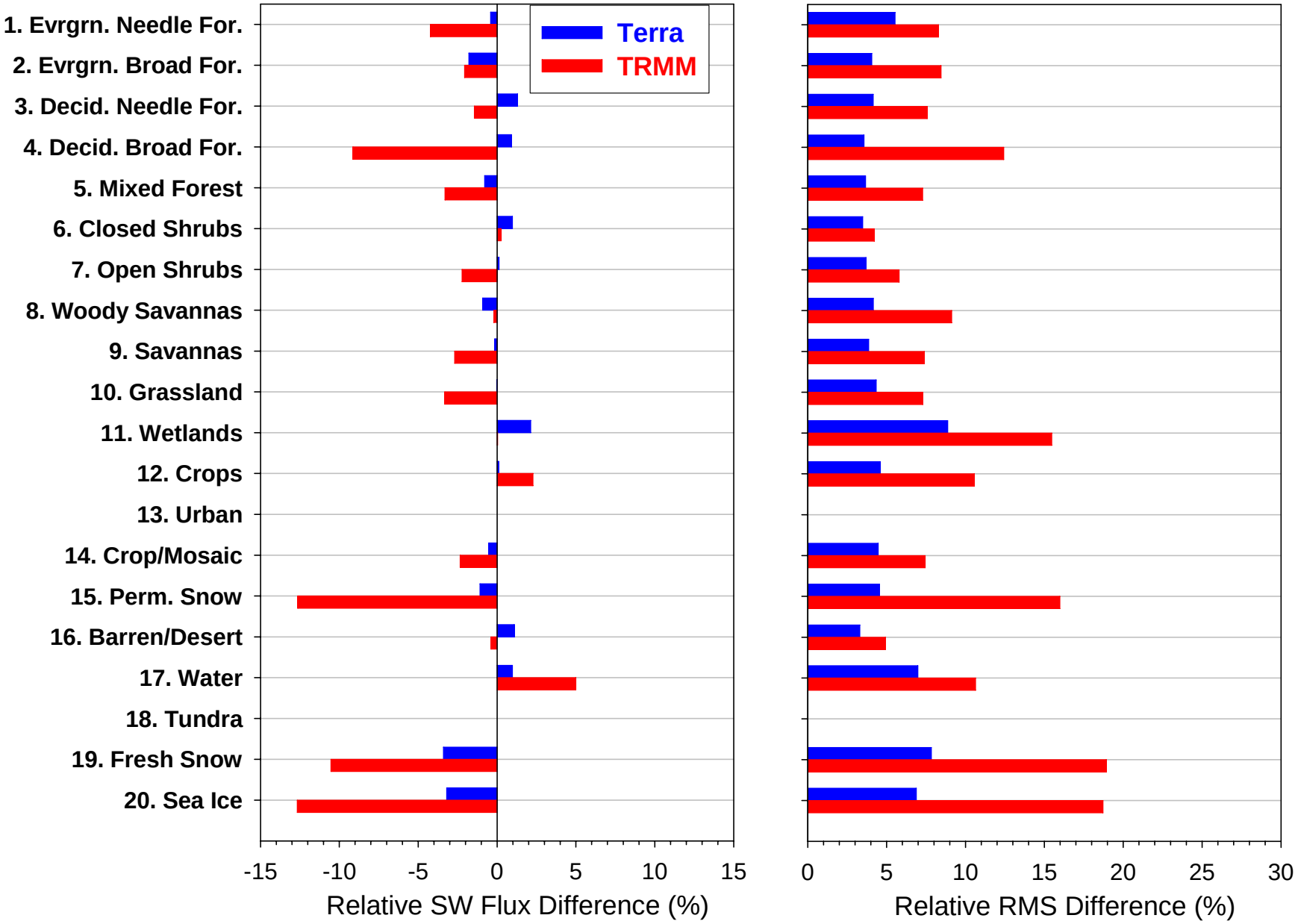
TOA Flux Consistency Tests

CERES-MODIS 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**
- **79 global alongtrack days over 4 years**

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



Cloud Layer Classification

	PCL			MCL			OVC		
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

PCL: CF = 0.1 - 40%	High: EP < 440 mb	Thin: τ < 3.35
MCL: CF = 40 – 99%	Mid: EP = 440 – 680 mb	Mod: τ = 3.35 – 22.63
OVC: CF = 99 – 100%	Low: EP > 680 mb	Thick: t > 22.63

CERES TOA Flux Consistency By Cloud Type

Relative RMS Flux Diff. [F(θ=50°-60°) – F(Nadir)]

OCEAN

SW: (Overall 3.95%)

CLR		PCL			MCL			OVC		
4.53	High								4.59	2.83
	Mid								4.69	5.17
	Low	5.70	9.27		3.98	5.22			3.13	2.97
		Thin	Mod	Thick	Thin	Mod	Thick	Thin	Mod	Thick

LW: (Overall 2.68%)

CLR		PCL			MCL			OVC		
0.95	High							11.38	8.06	6.75
	Mid					6.58			4.23	4.10
	Low	1.11	1.34		1.47	2.67			2.06	2.26
		Thin	Mod	Thick	Thin	Mod	Thick	Thin	Mod	Thick

CERES TOA Flux Consistency By Cloud Type

Relative RMS Flux Diff. [F(θ=50°-60°) – F(Nadir)]

LAND AND DESERT

SW: (Overall 4.16%)

CLR		PCL			MCL			OVC		
3.65	High								7.70	4.23
	Mid					6.60				3.35
	Low	9.78	7.99			5.77			2.92	4.61
		Thin	Mod	Thick	Thin	Mod	Thick	Thin	Mod	Thick

LW: (Overall 2.11%)

CLR		PCL			MCL			OVC		
1.98	High								10.18	7.38
	Mid					5.29				2.04
	Low	2.38	2.69			2.06			3.72	2.35
		Thin	Mod	Thick	Thin	Mod	Thick	Thin	Mod	Thick

CERES TOA Flux Consistency By Cloud Type

Relative RMS Flux Diff. [F(θ=50°-60°) – F(Nadir)]

SNOW AND SEA-ICE

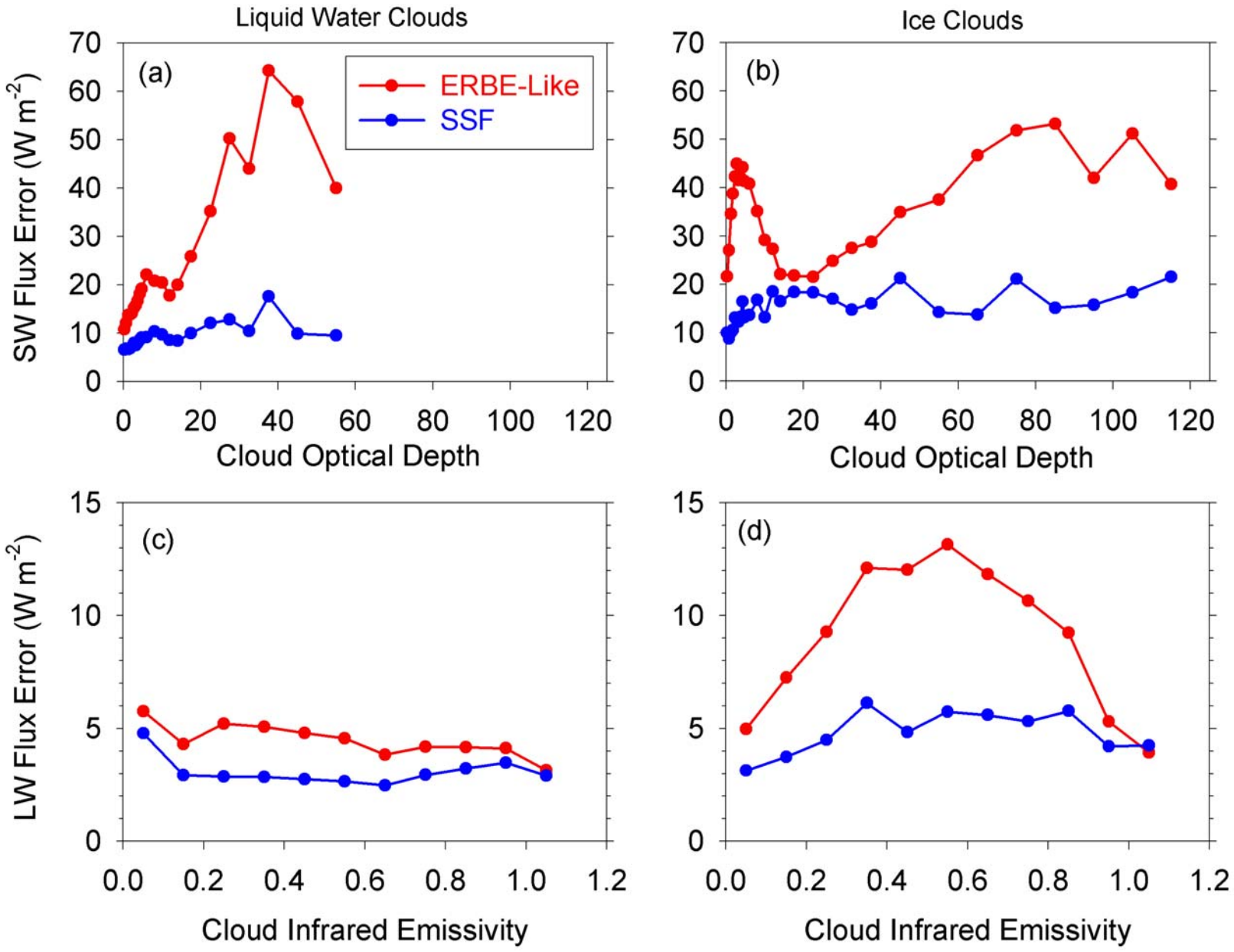
SW: (Overall 7.85%)

CLR		PCL			MCL			OVC		
6.28	High							8.75	9.23	
	Mid	5.77			7.76				7.63	3.59
	Low	11.74	25.94		9.75	12.49			5.56	5.92
		Thin	Mod	Thick	Thin	Mod	Thick	Thin	Mod	Thick

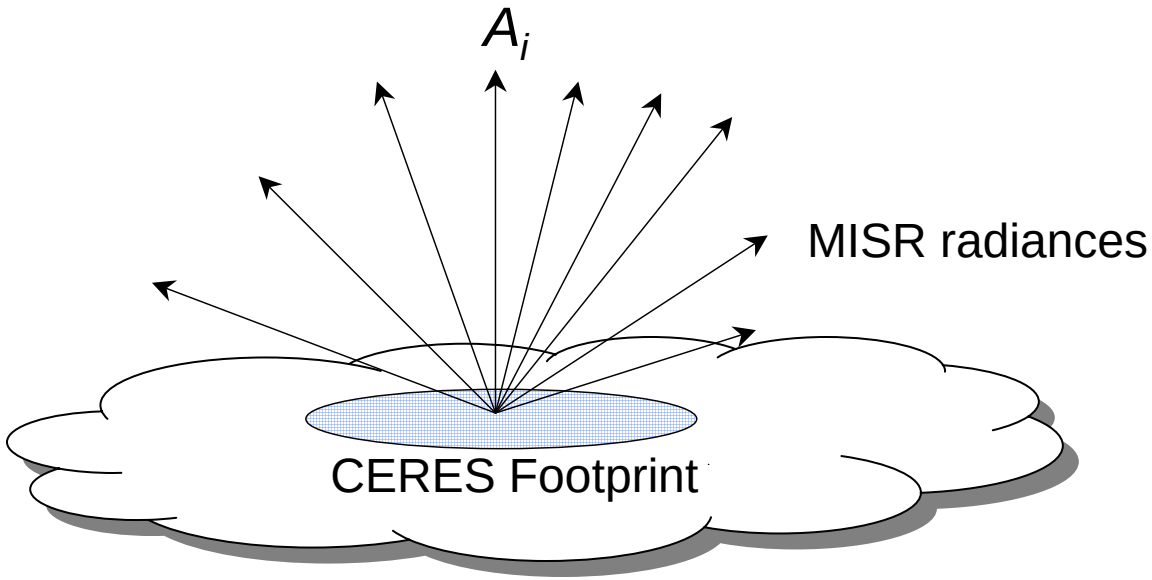
LW: (Overall 2.56%)

CLR		PCL			MCL			OVC		
2.51	High							5.18	2.82	
	Mid	1.98	4.36		2.30	5.44		3.22	3.99	
	Low	2.42	2.07		2.32	2.79			2.16	2.65
		Thin	Mod	Thick	Thin	Mod	Thick	Thin	Mod	Thick

Instantaneous TOA Flux Error by Cloud Property

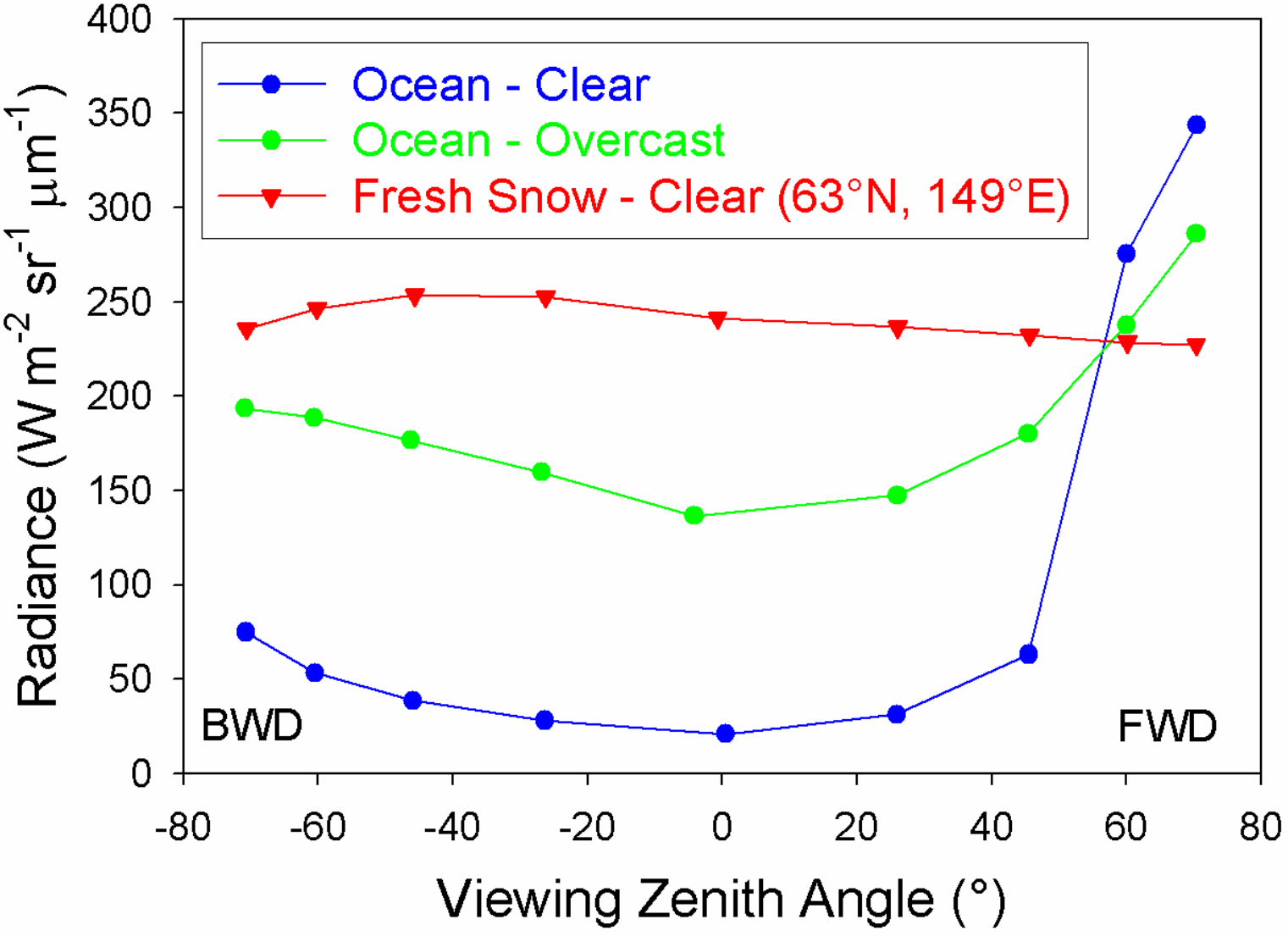


CERES-MISR Albedo Comparison

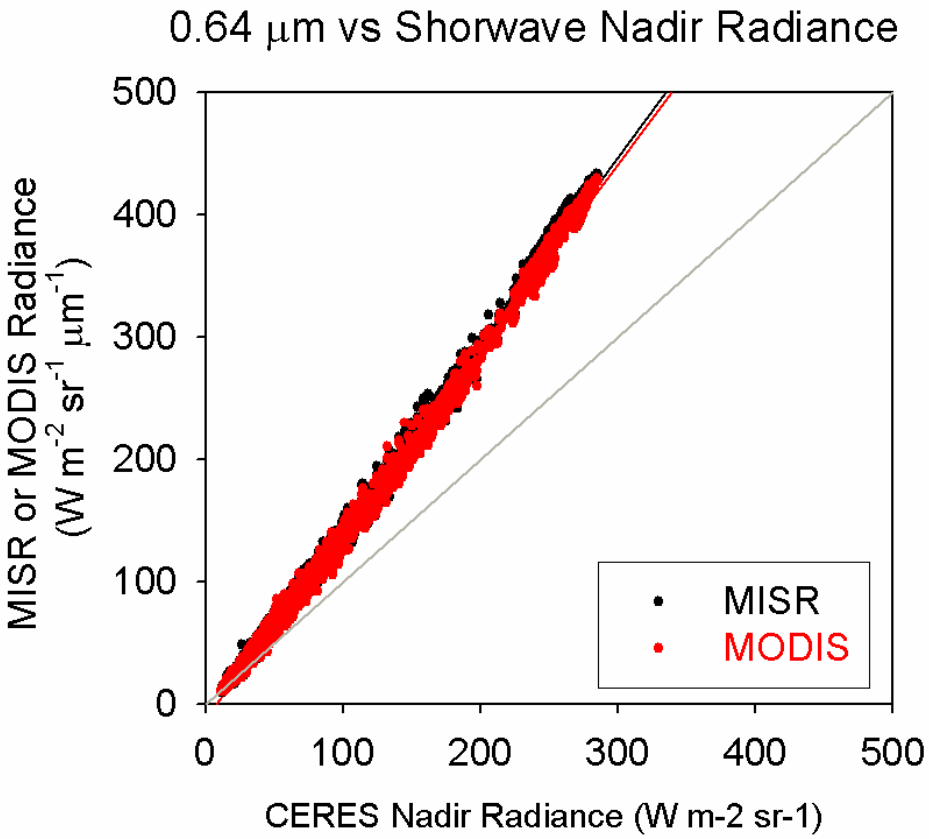


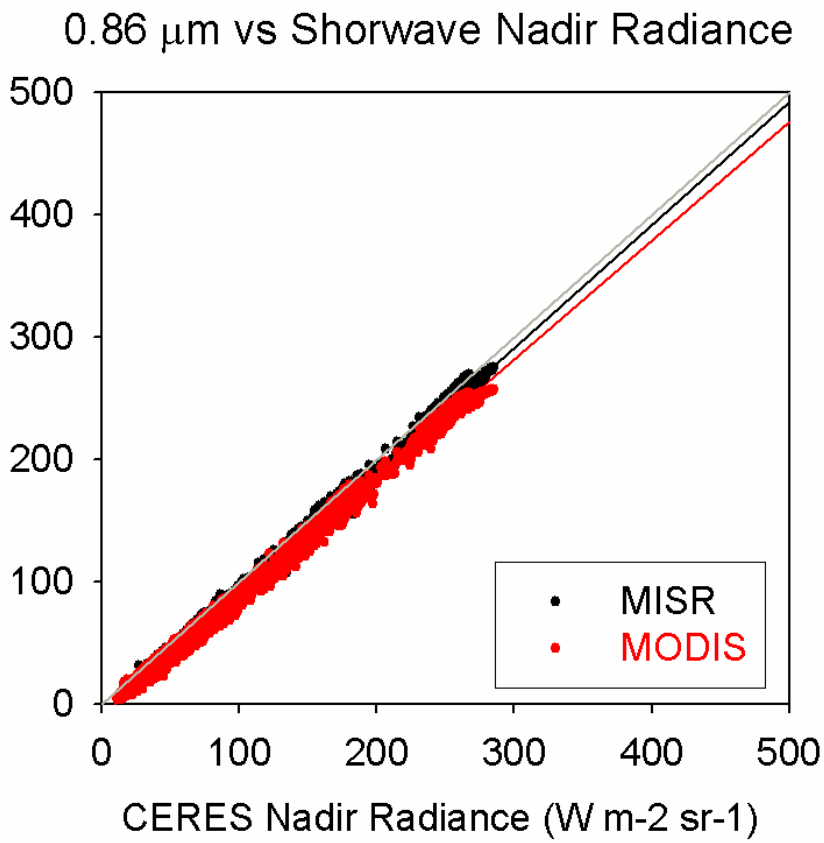
- Convert MISR radiances and albedos to broadband SW.
- Are CERES and MISR albedos consistent?
- Infer TOA albedo from every MISR angle using CERES ADMs
- Are albedos from different angles consistent?
- How do differences depend upon cloud type and degree of anisotropy and inhomogeneity?

0.558 μm MISR Anisotropy Over CERES Footprints (θ_o=54°; 20° off Principal Plane; April 12, 2000)



CERES, MODIS and MISR Radiance Comparison





ES8 and SSF Comparisons

24-h Monthly Mean TOA Fluxes from Instantaneous CERES Fluxes (e.g., SSF, ES8)

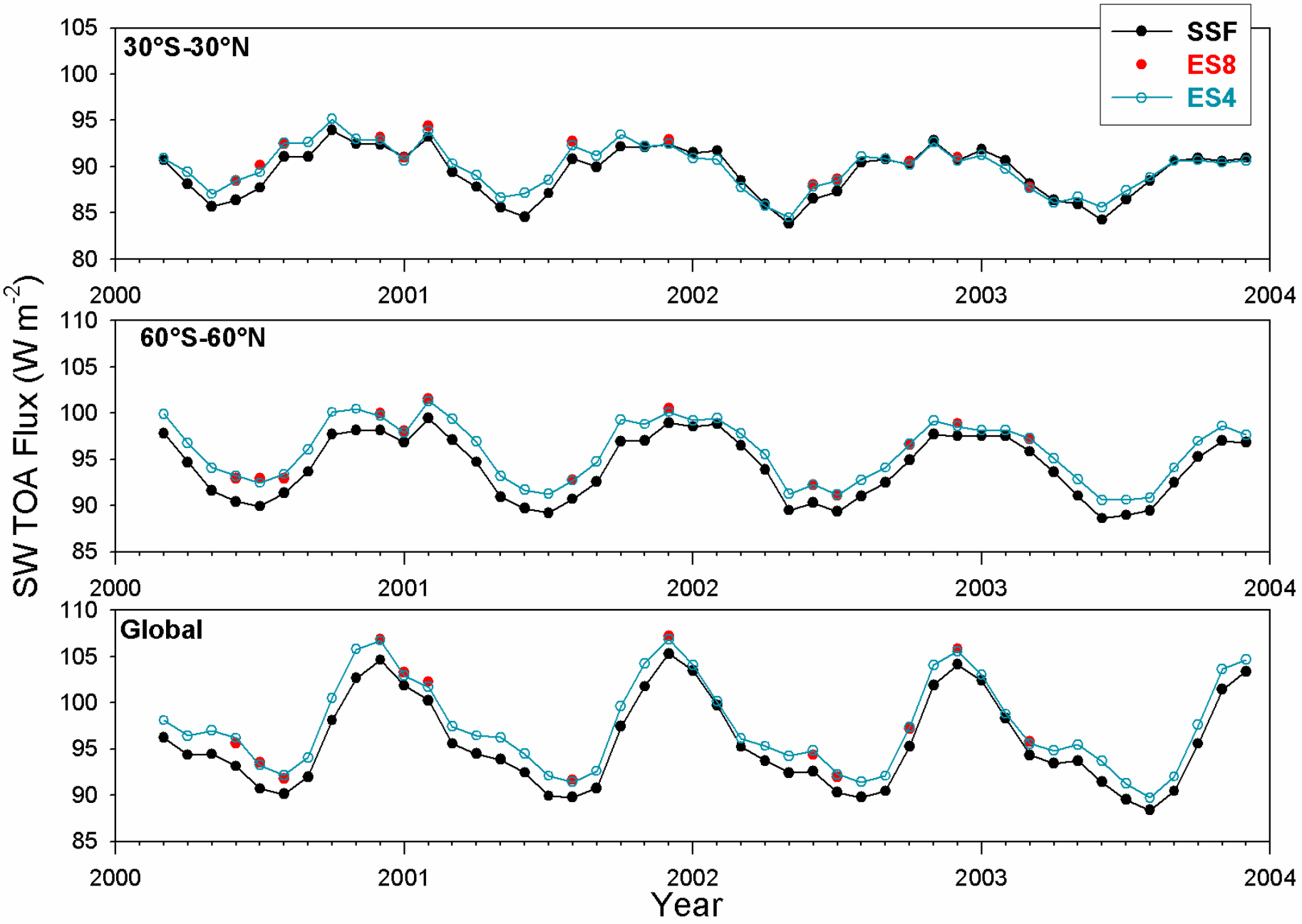
- Apply CERES Terra ADMs to determine TOA flux from every CERES footprint in CERES SSF product.

- Convert every CERES TOA flux to a 24-h average flux using CERES TRMM diurnal albedo models (assume constant meteorology).

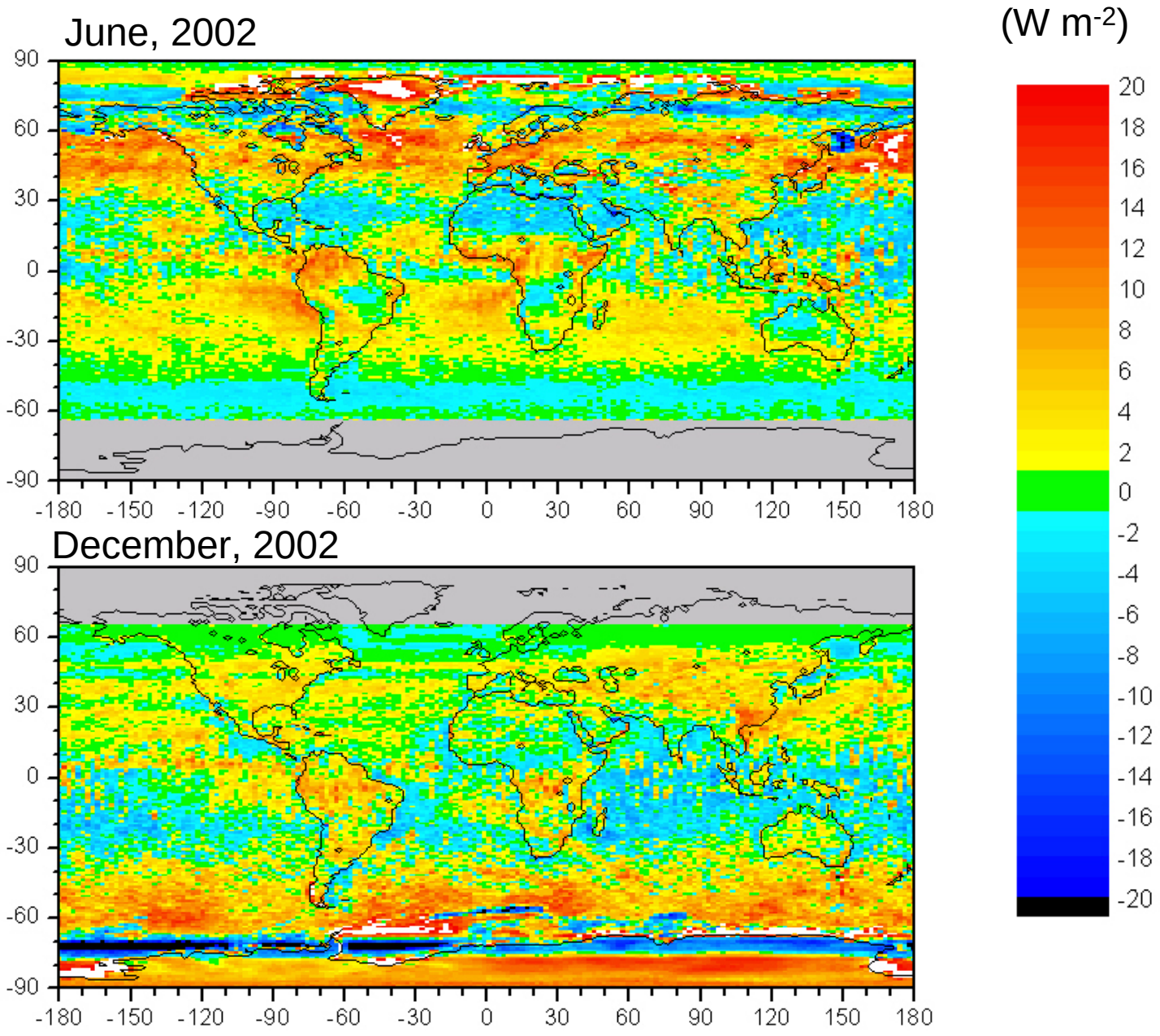
- Determine gridded (1°x1° latitude-longitude) monthly mean maps of SW TOA Flux.

- Repeat these steps for CERES ES8 (ERBE-Like) instantaneous TOA fluxes and ERBE diurnal albedo models.

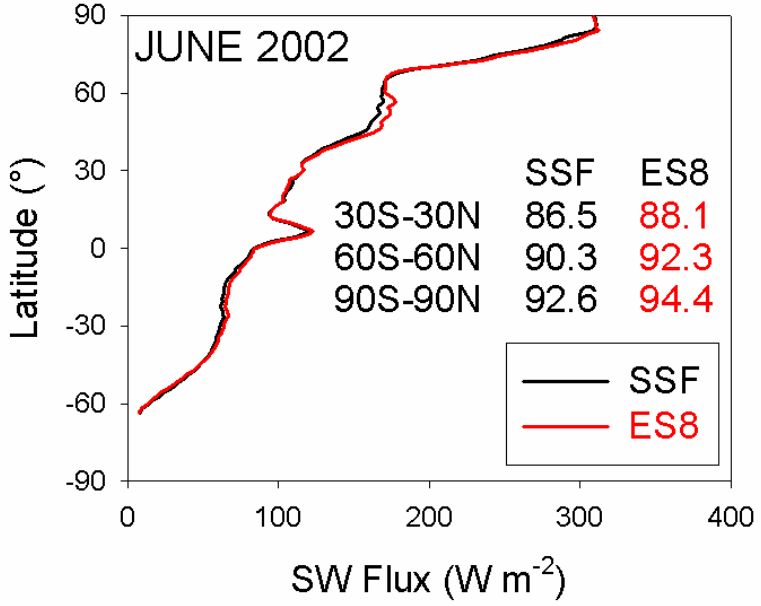
Monthly Mean All-Sky SW TOA Flux Time Series: FM1 (With Dirunal Averaging)

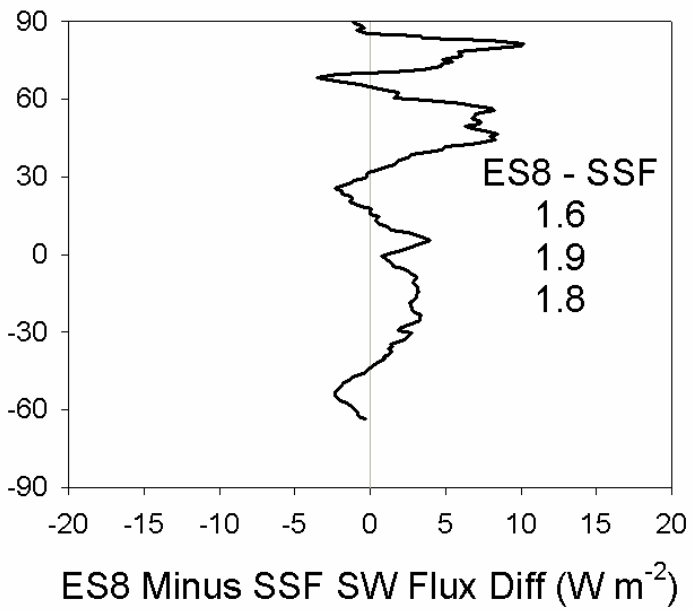


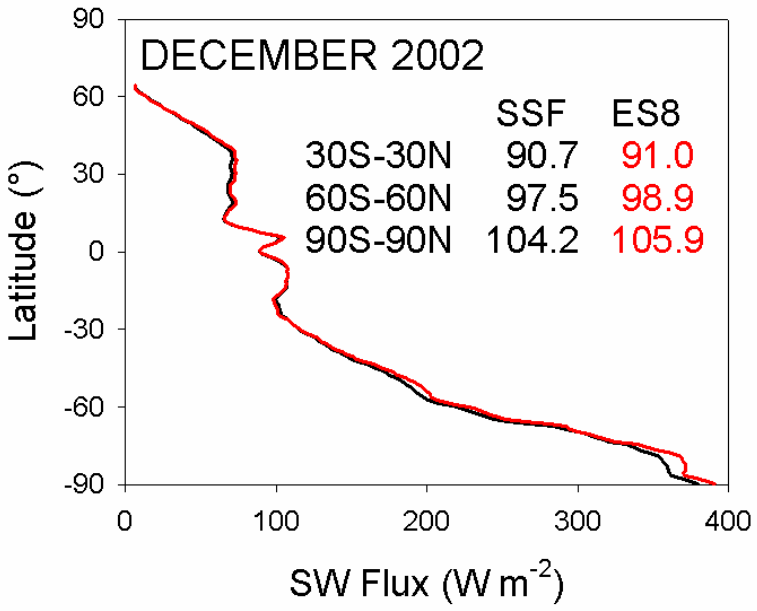
ES8 Minus SSF SW TOA Flux Difference (24-h Avg)

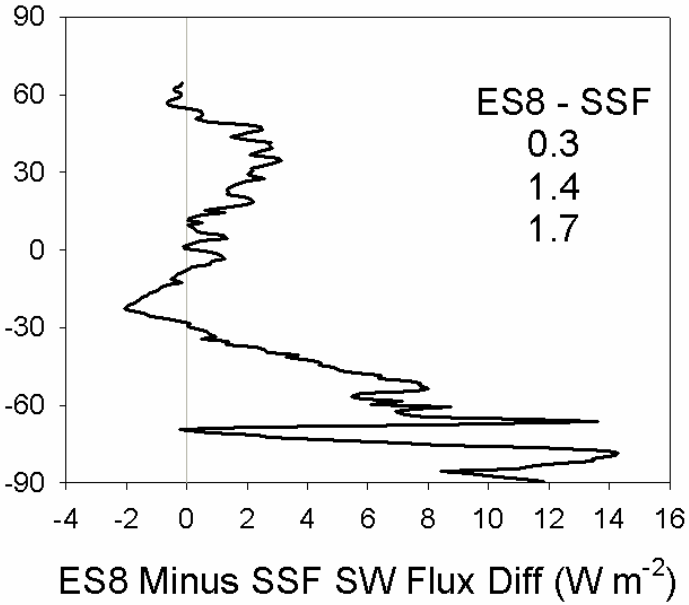


FM1 ES8 and SSF SW TOA Flux Comparison

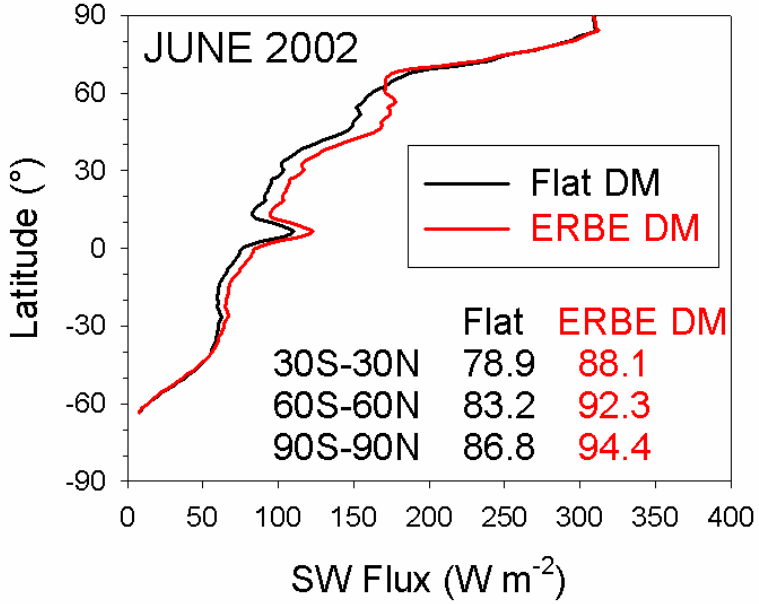


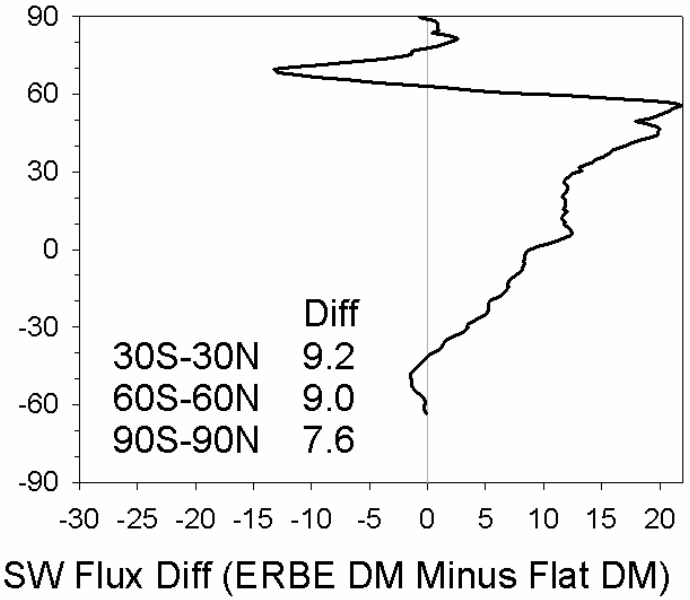


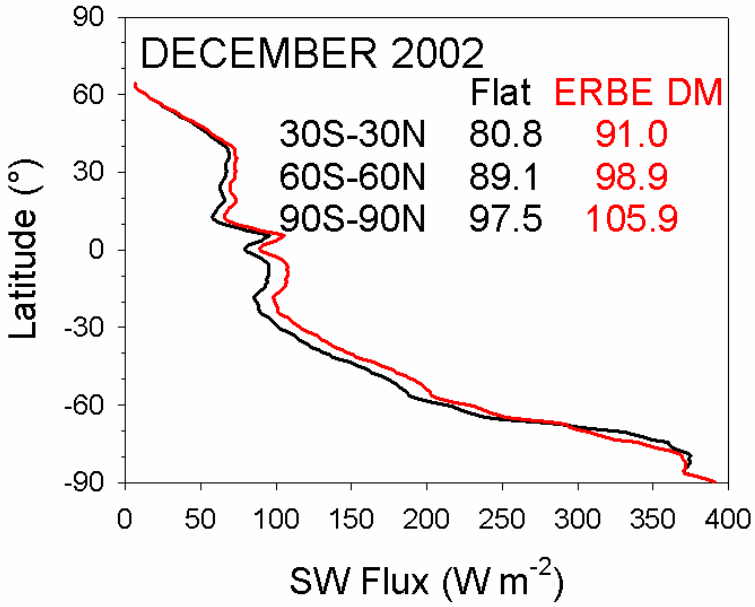


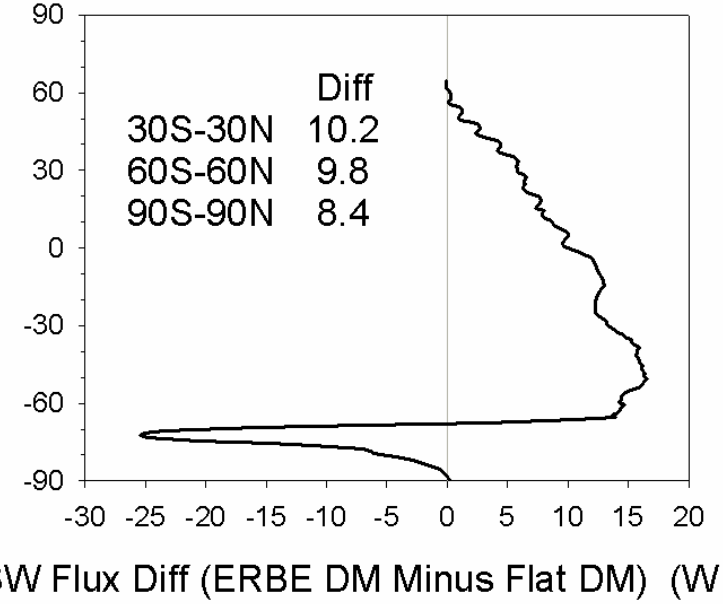


SW TOA Flux Sensitivity to Diurnal Albedo Model (ERBE ADM; ERBE DM)

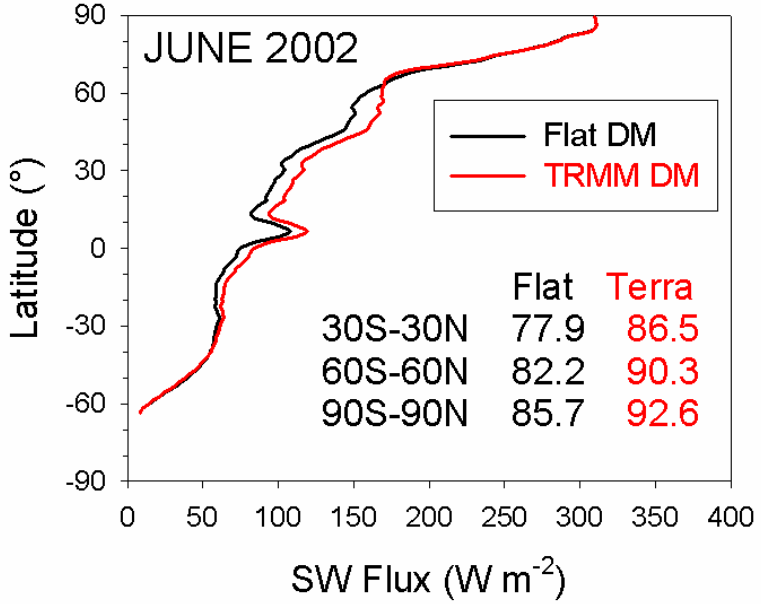


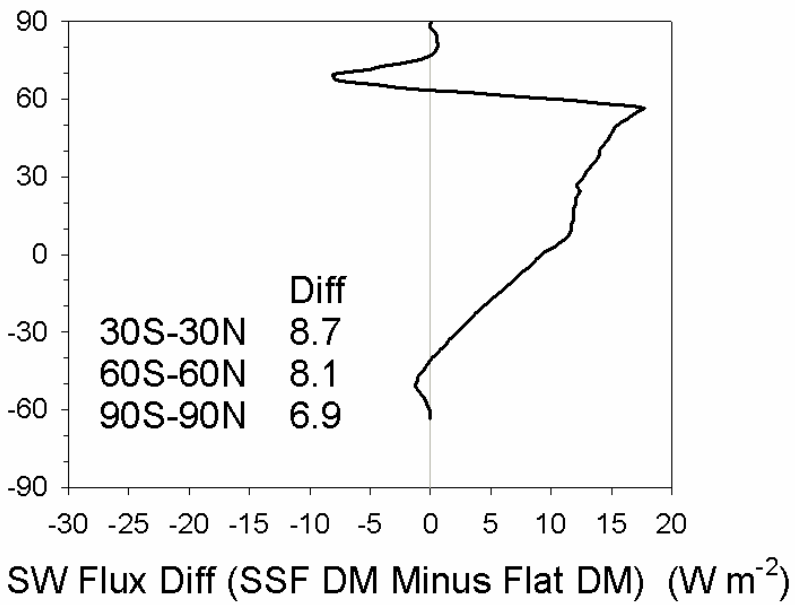


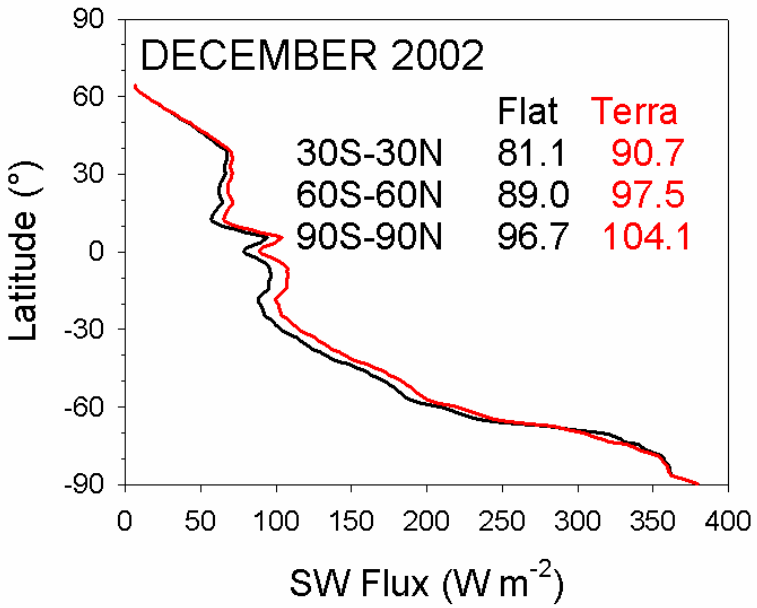


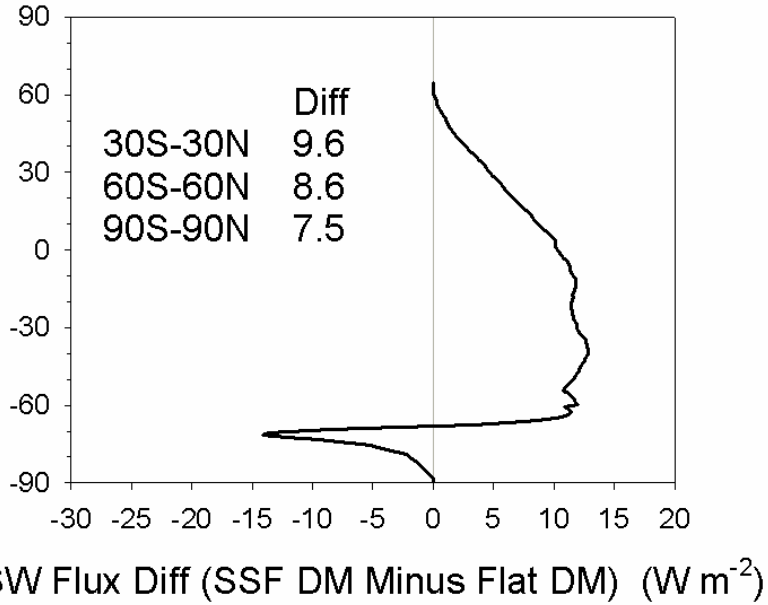


SW TOA Flux Sensitivity to Diurnal Albedo Model (SSF ADM; TRMM+Terra Snow DM)

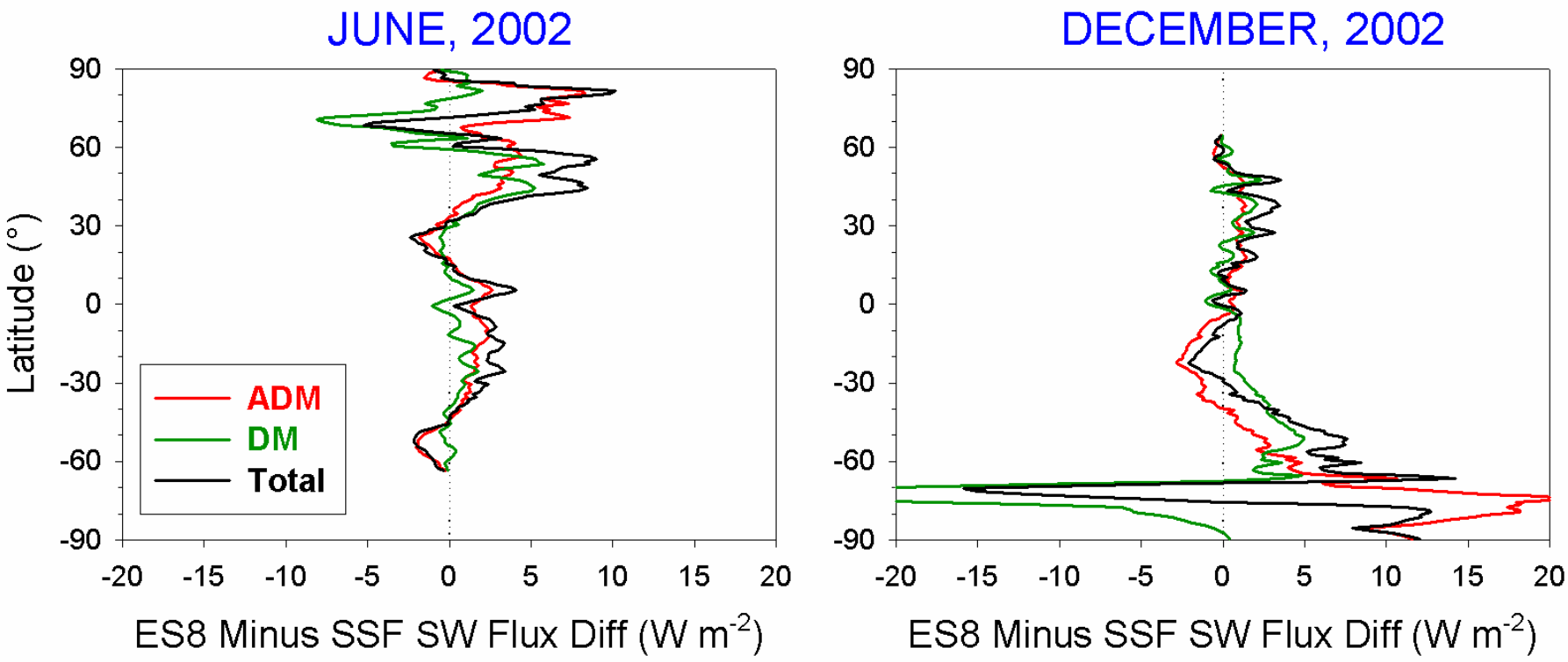




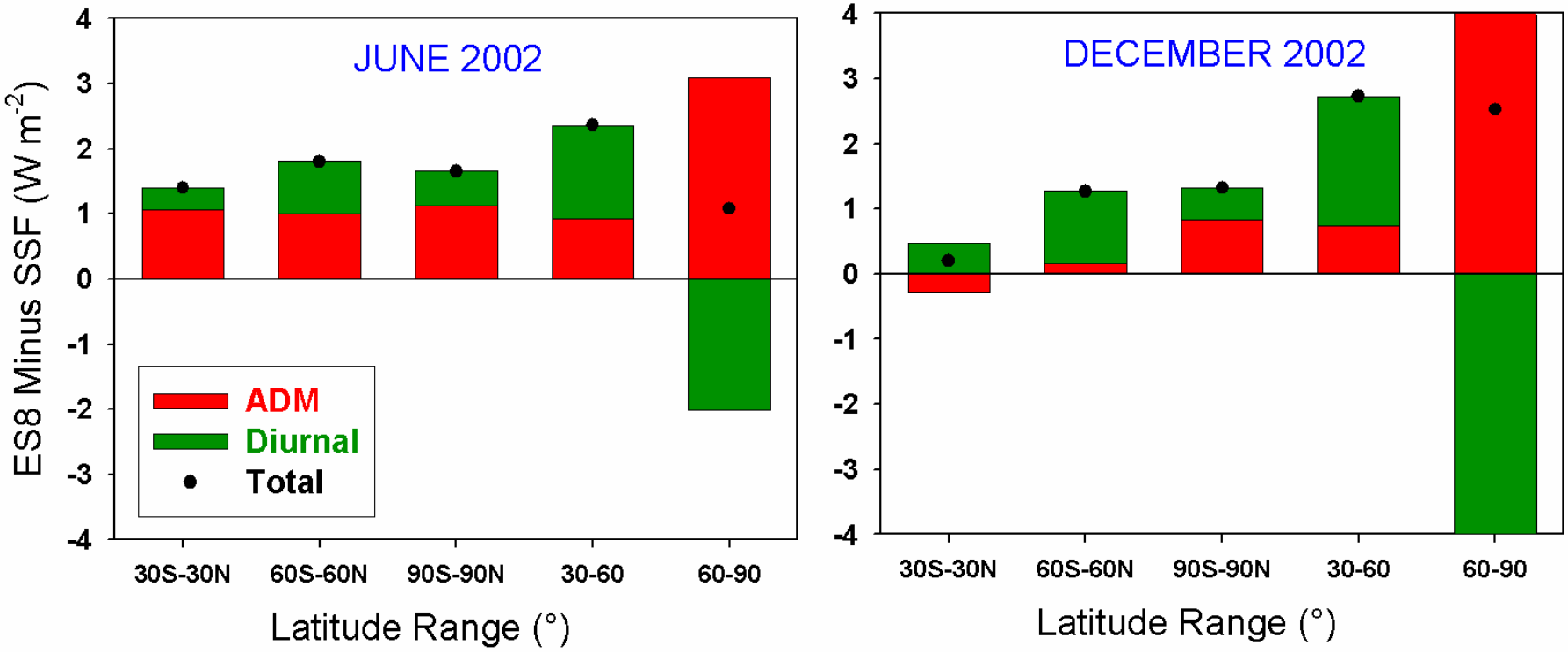


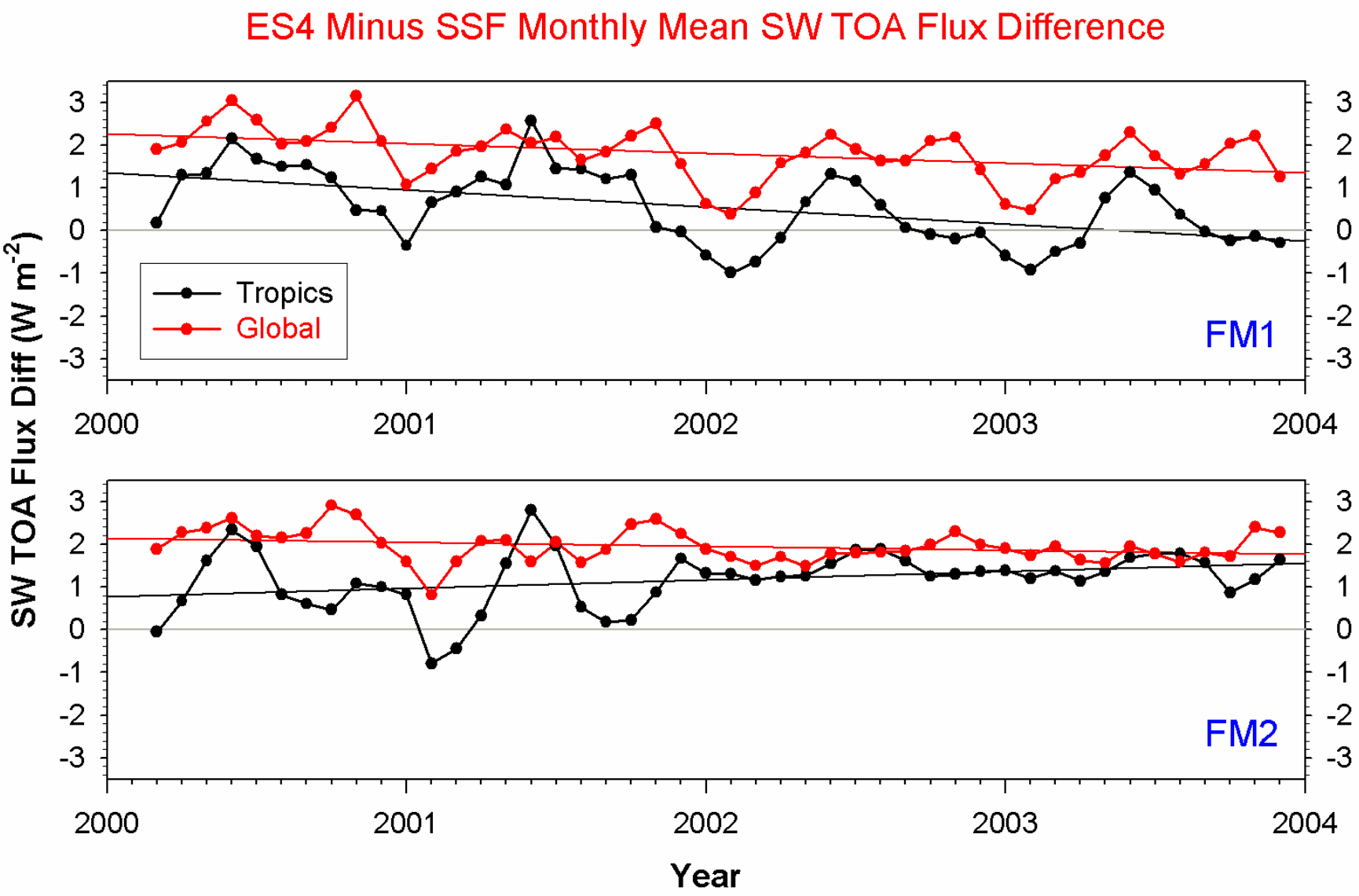


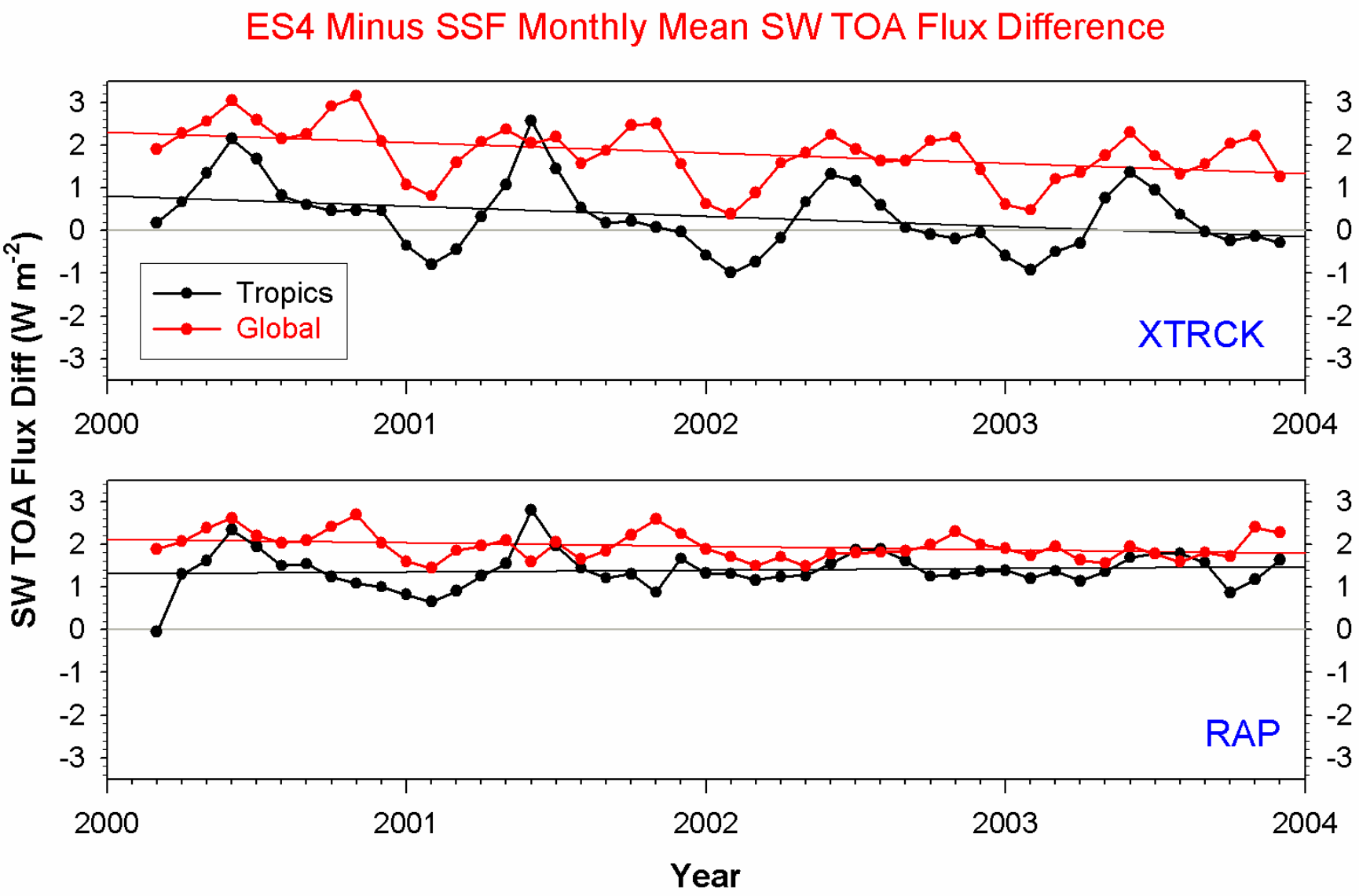
FM1 ES8 and SSF SW TOA Flux Comparison
(Sensitivity to ADM and Diurnal Albedo Model Differences)



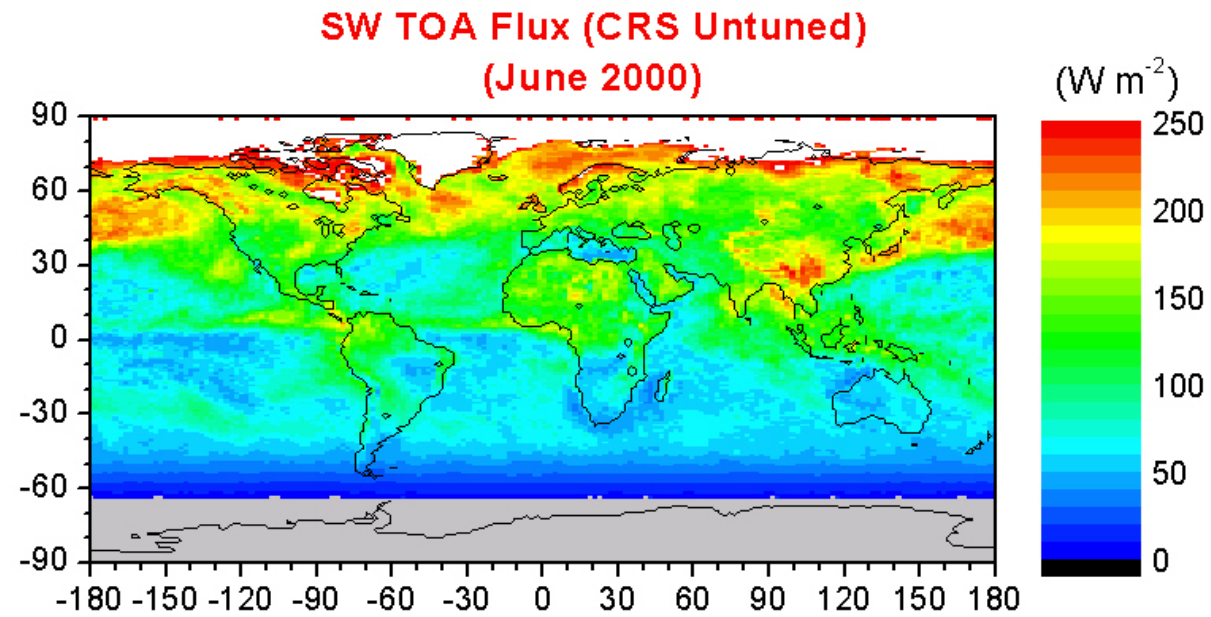
FM1 ES8 and SSF Zonal Average SW TOA Flux Differences

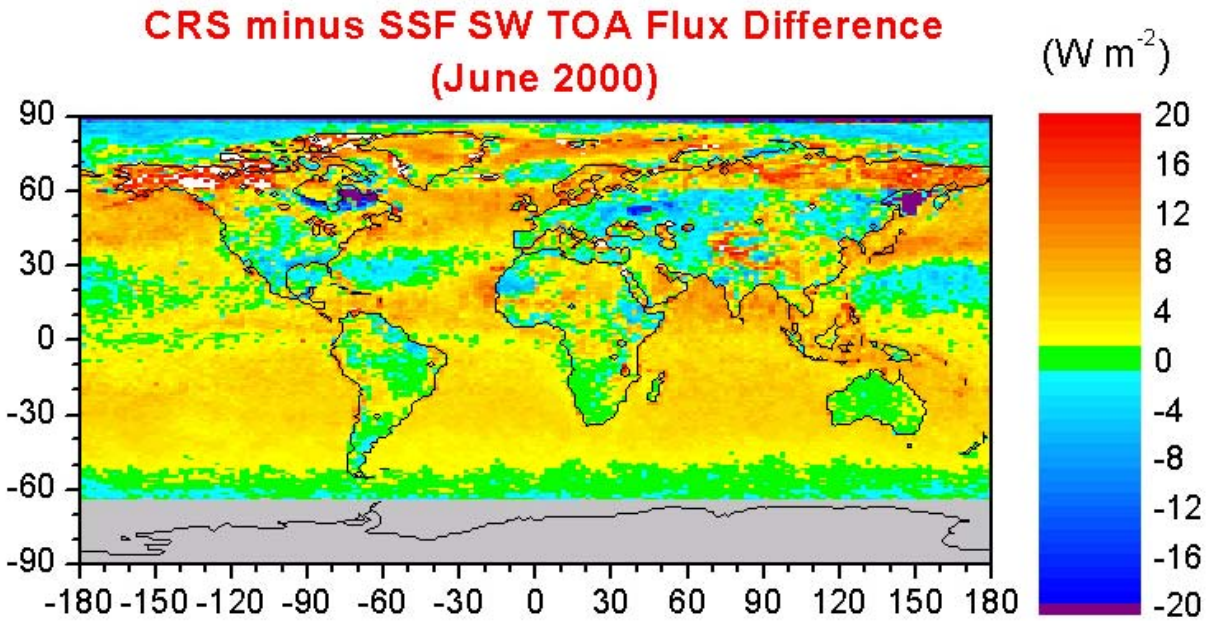


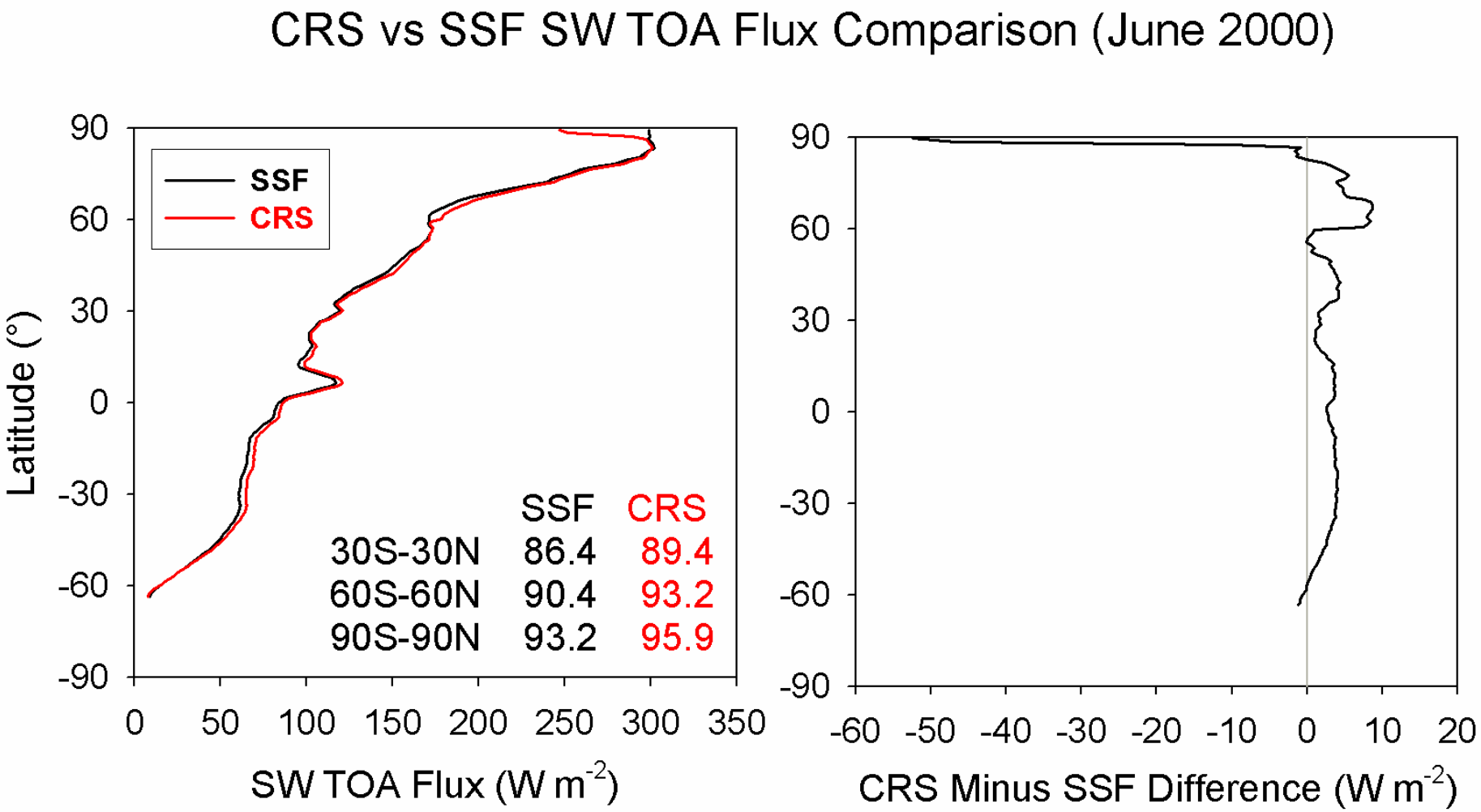

ES4 Minus SSF Monthly Mean SW TOA Flux Difference
SW TOA Flux Diff (W m-2)
Tropics
Global
FM1
FM2
3
2
1
0
-1
-2
-3
2000
2001
2002
2003
2004
Year


ES4 Minus SSF Monthly Mean SW TOA Flux Difference
SW TOA Flux Diff (W m-2)
Tropics
Global
XTRCK
RAP
2000
2001
2002
2003
2004
Year

SSF and CRS Flux Comparisons

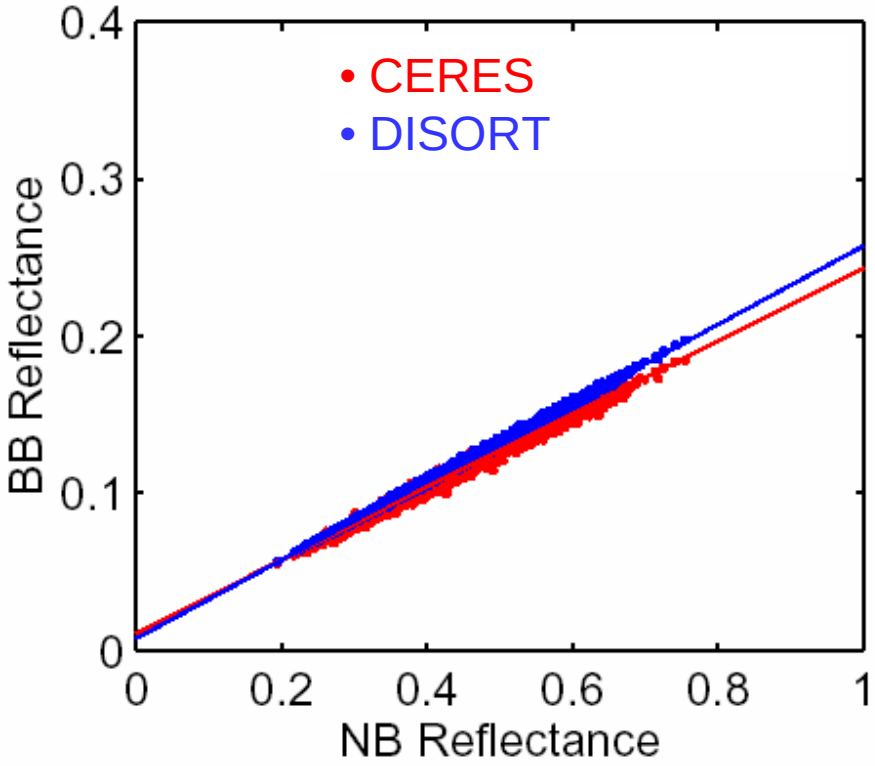

SW TOA Flux (CRS Untuned)
(June 2000)
(W m-2)
250
200
150
100
50
0
90
60
30
0
-30
-60
-90
-180 -150 -120 -90 -60 -30 0 30 60 90 120 150 180

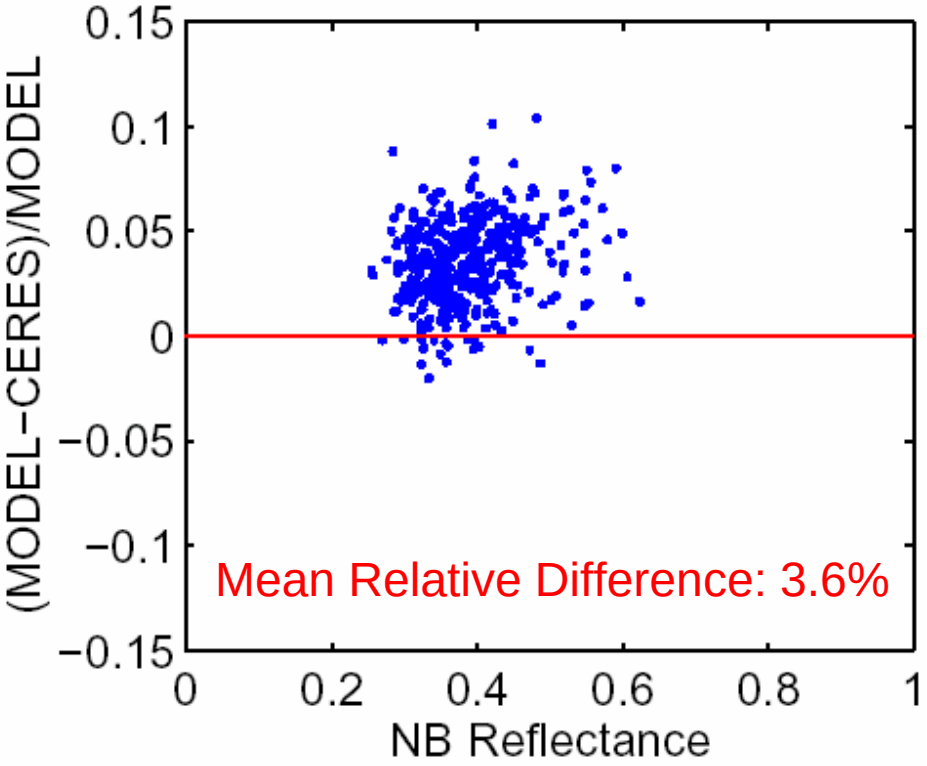

CRS minus SSF SW TOA Flux Difference
(June 2000)
(W m-2)
20
16
12
8
4
0
-4
-8
-12
-16
-20
90
60
30
0
-30
-60
-90
-180 -150 -120 -90 -60 -30 0 30 60 90 120 150 180


CRS vs SSF SW TOA Flux Comparison (June 2000)
SSF
CRS
Latitude (°)
90
60
30
0
-30
-60
-90
0
50
100
150
200
250
300
350
SW TOA Flux (W m-2)
SSF CRS
30S-30N 86.4 89.4
60S-60N 90.4 93.2
90S-90N 93.2 95.9
-60
-50
-40
-30
-20
-10
0
10
20
CRS Minus SSF Difference (W m-2)

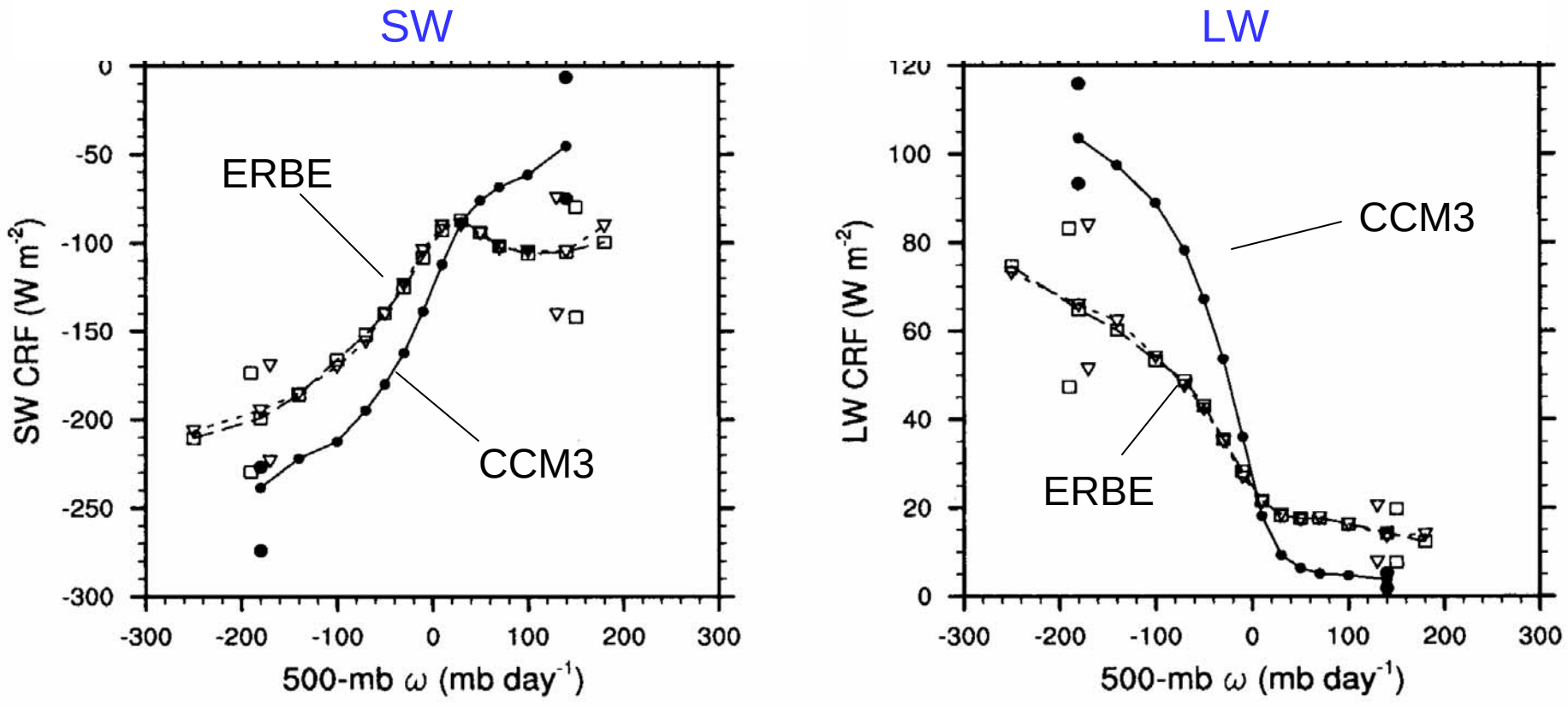
CERES SW Reflectance vs DISORT Reflectance

(OVC Liquid Water Clouds; θ_o=25°-30°; θ=20°-40°; ϕ=30°-60°)



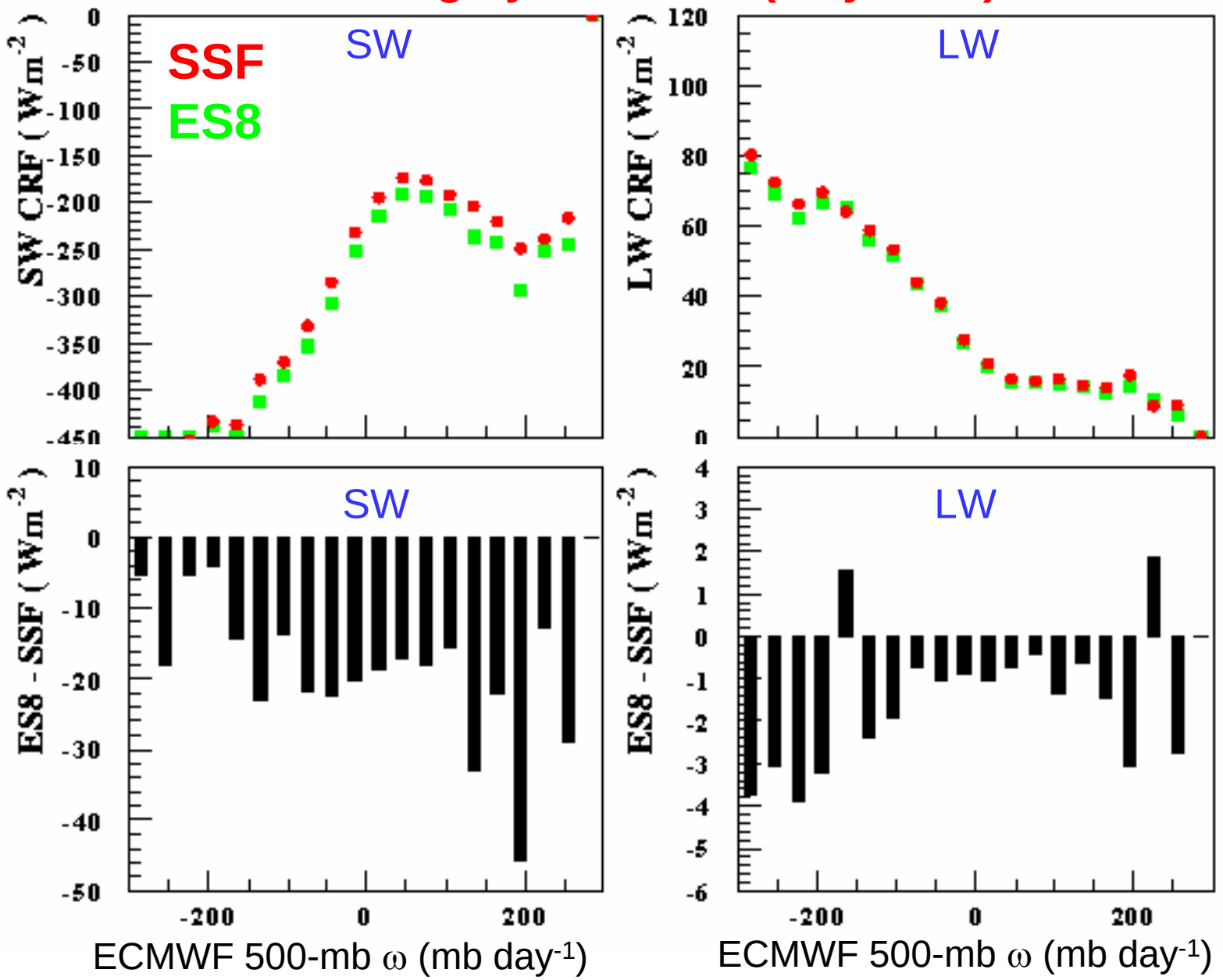


Mean SW and LW Cloud Radiative Forcing
(North Pacific 30°-60°; 160° -220°E; July 1985-1989)



Norris and Weaver, 2001

CERES SSF vs ERBE-Like Avg. Inst. Cloud Radiative Forcing by 500-mb ω (July 2000)



Plans For Aqua

- Produce final CERES Aqua Edition2 ADMs and validation results by the fall 2005 CERES STM.

- Aqua ADMs will use 2 yrs of Aqua Edition1B SSFs and will be based on the same strategy as CERES Terra Edition2B ADMs

BACKUP SLIDES

$$\hat{F}_{24\,\mathrm{h}} = \frac{\hat{A}[\theta_o(t_o)]}{\alpha[\mathbf{x}_\mathbf{M}(t_o),\theta_o(t_o)]}\frac{1}{N_t}\sum_{i=1}^{N_t}\alpha[\mathbf{x}_\mathbf{G}(t_i),\theta_o(t_i)]\mu_o(t_i)E_o\left[\frac{\overline{\alpha}_\mathbf{M}}{\overline{\alpha}_\mathbf{G}}\right]$$

$\hat{A}$=Instantaneous 1°×1° TOA albedo from CERES

t_o=time of CERES observation

t_i=time corresponding to i^{th} time-step in 24-h integration

θ_o=Solar zenith angle

α=CERES TRMM directional model albedo

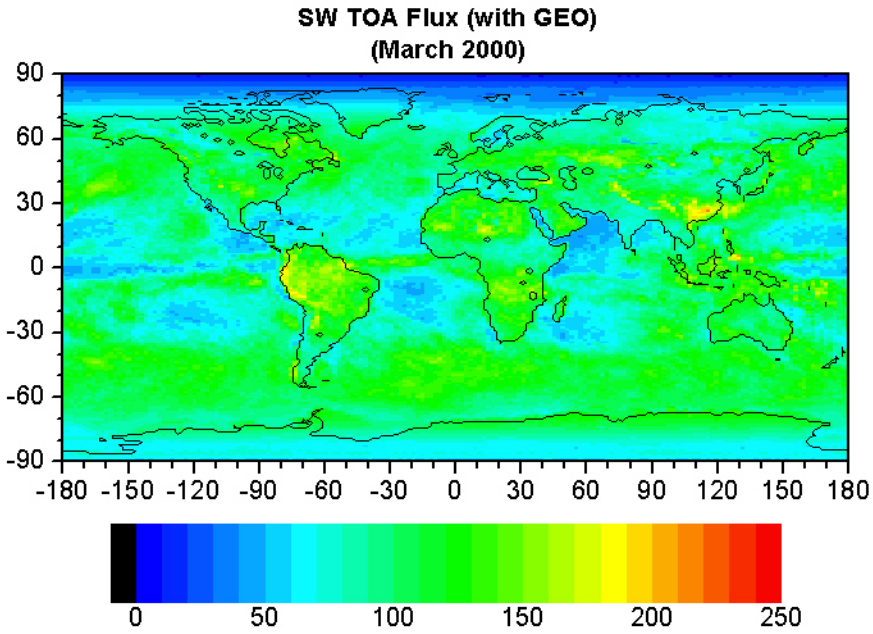
$\boldsymbol{x}_G$=$\boldsymbol{x}(f_G, \tau_G, Ph_G, \ldots)$=CERES TRMM ADM scene type from GEO

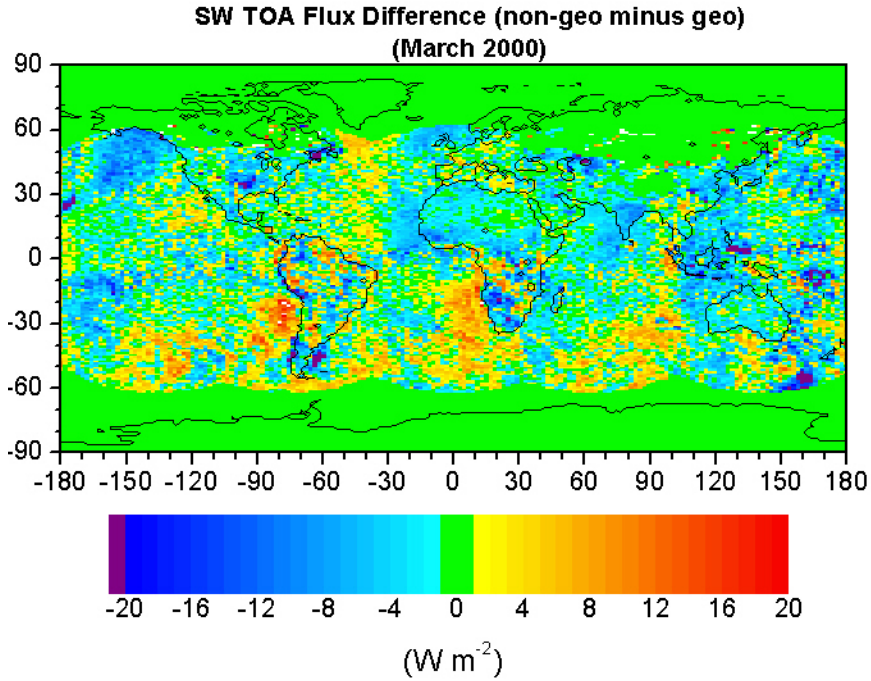
$\boldsymbol{x}_M$=$\boldsymbol{x}(f_M, \tau_M, Ph_M, \ldots)$=CERES TRMM ADM scene type from MODIS

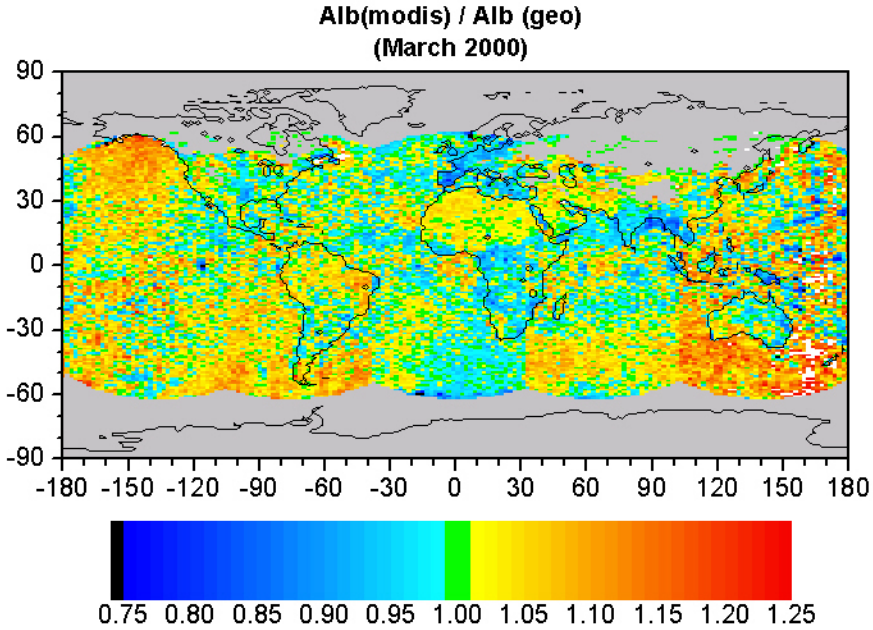
$f, \tau, Ph, \ldots$=GEO or MODIS retrievals needed to determine scene type

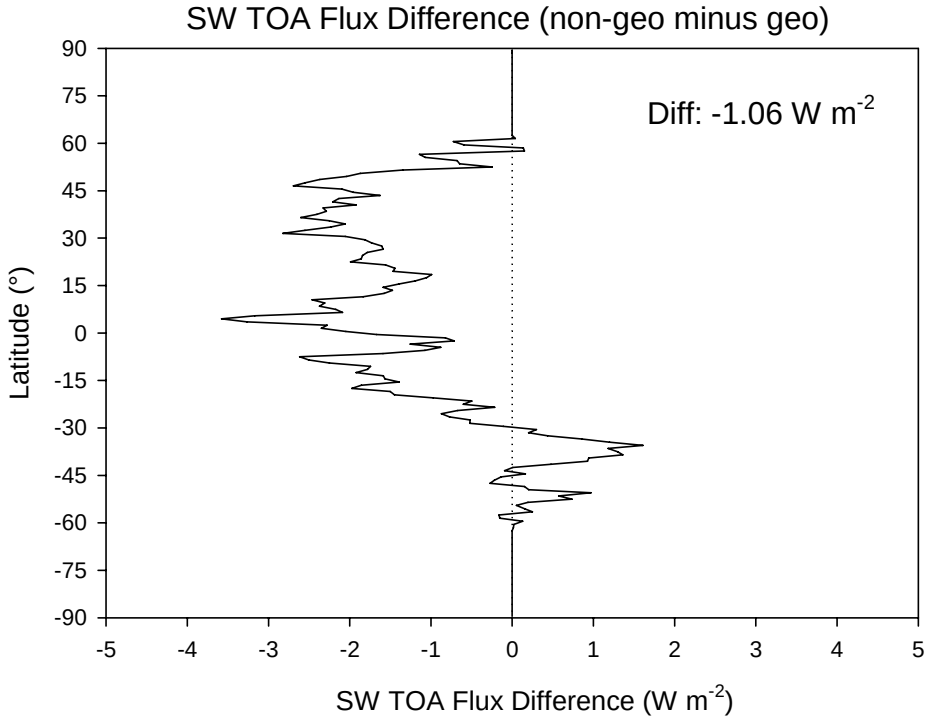
E_o=Solar constant

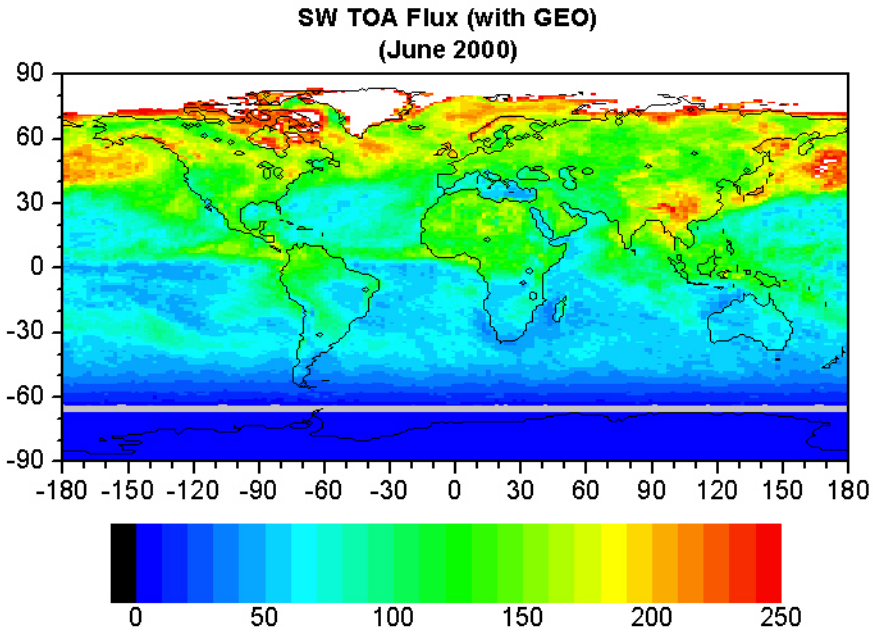
$\left[\frac{\overline{\alpha}_\mathbf{M}}{\overline{\alpha}_\mathbf{G}}\right]$=Correction factor to account for scene identification inconsistency between GEO and MODIS (e.g., due to calibration; retrieval biases...)

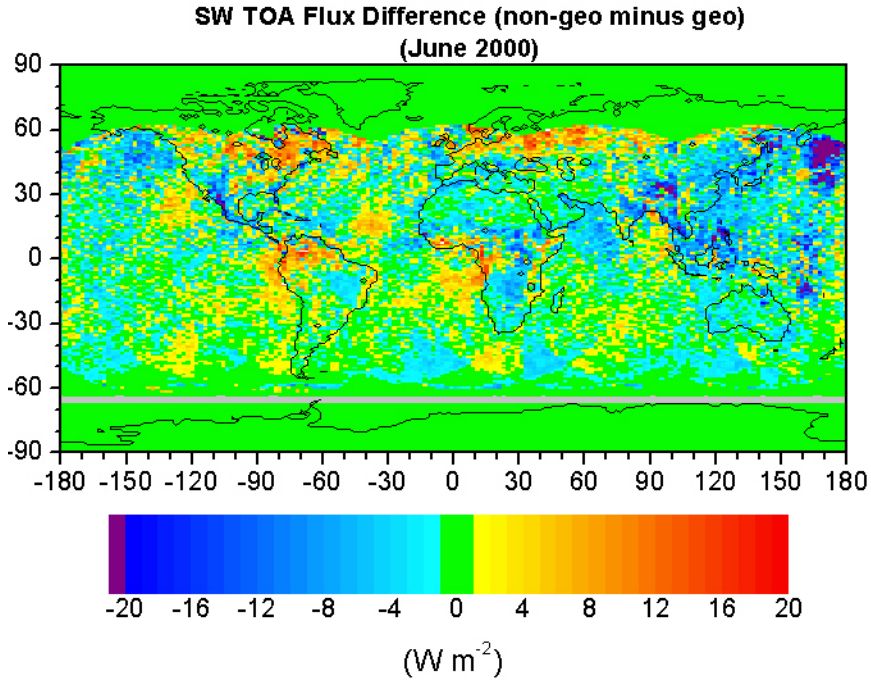

SW TOA Flux (with GEO)
(March 2000)
90
60
30
0
-30
-60
-90
-180 -150 -120 -90 -60 -30 0 30 60 90 120 150 180
0 50 100 150 200 250

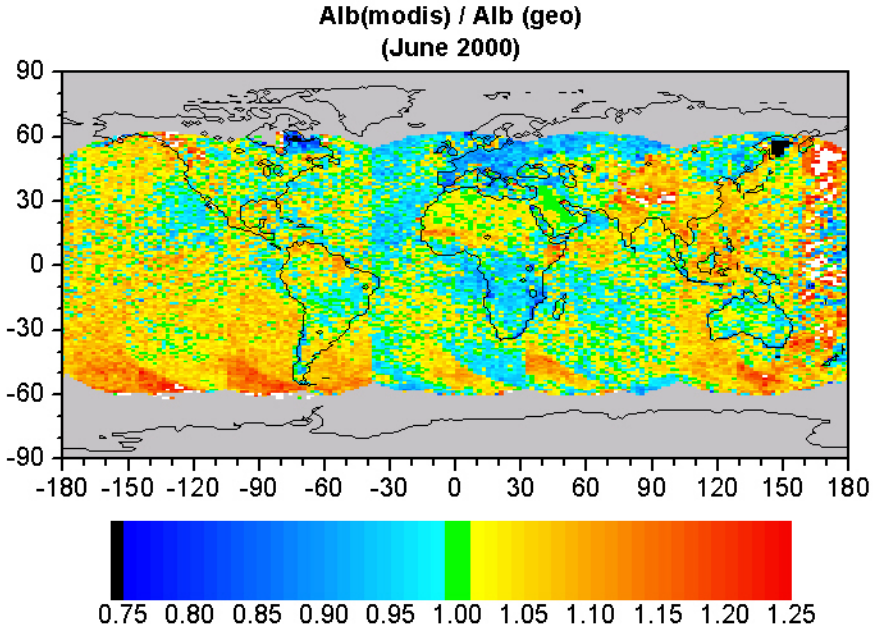

SW TOA Flux Difference (non-geo minus geo)
(March 2000)
90
60
30
0
-30
-60
-90
-180 -150 -120 -90 -60 -30 0 30 60 90 120 150 180
-20 -16 -12 -8 -4 0 4 8 12 16 20
(W m-2)

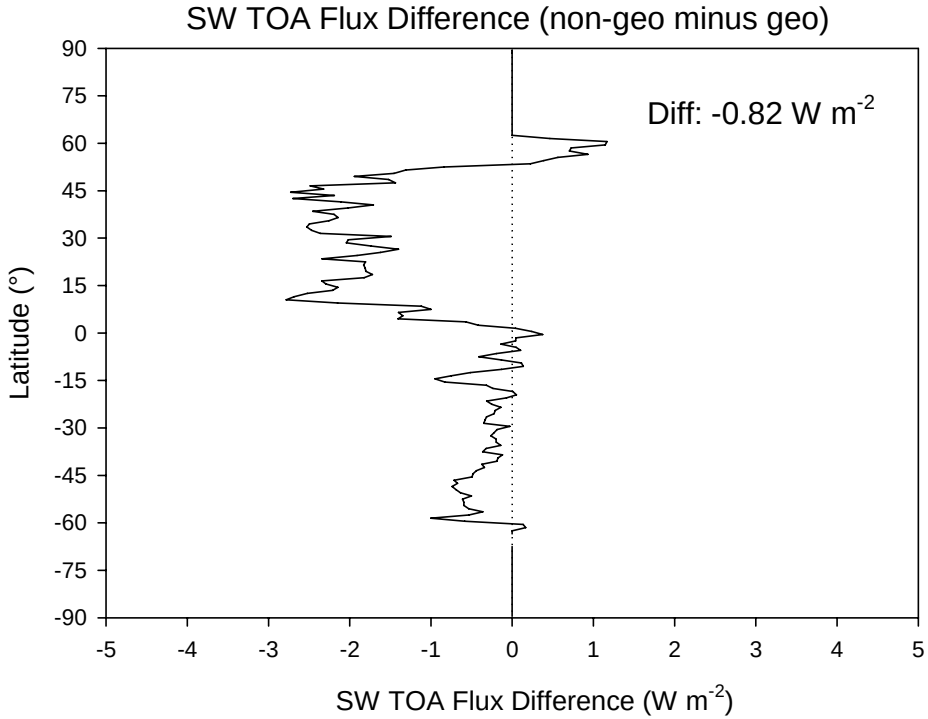

Alb(modis) / Alb (geo)
(March 2000)
90
60
30
0
-30
-60
-90
-180 -150 -120 -90 -60 -30 0 30 60 90 120 150 180
0.75 0.80 0.85 0.90 0.95 1.00 1.05 1.10 1.15 1.20 1.25

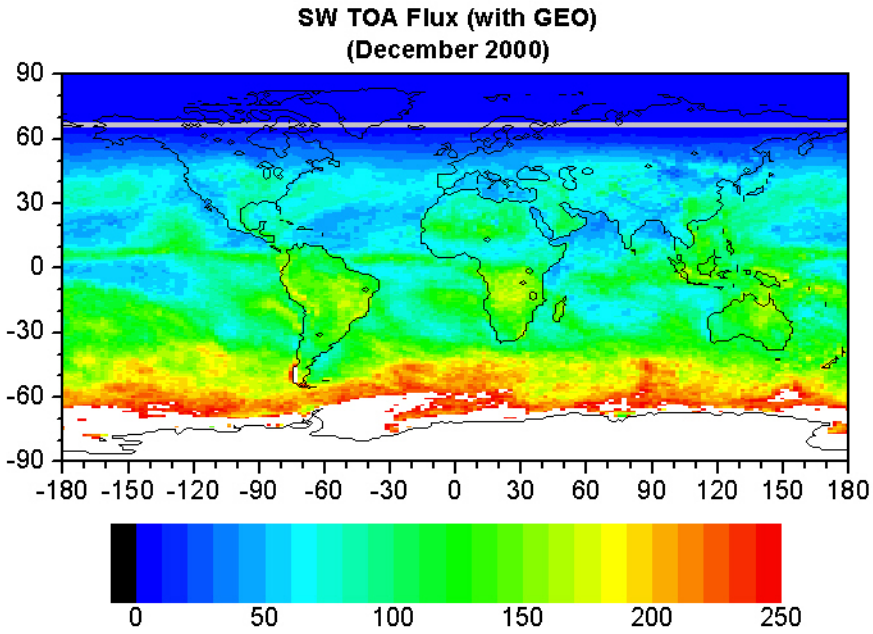

SW TOA Flux Difference (non-geo minus geo)
Diff: -1.06 W m-2
Latitude (°)
90
75
60
45
30
15
0
-15
-30
-45
-60
-75
-90
-5 -4 -3 -2 -1 0 1 2 3 4 5
SW TOA Flux Difference (W m-2)

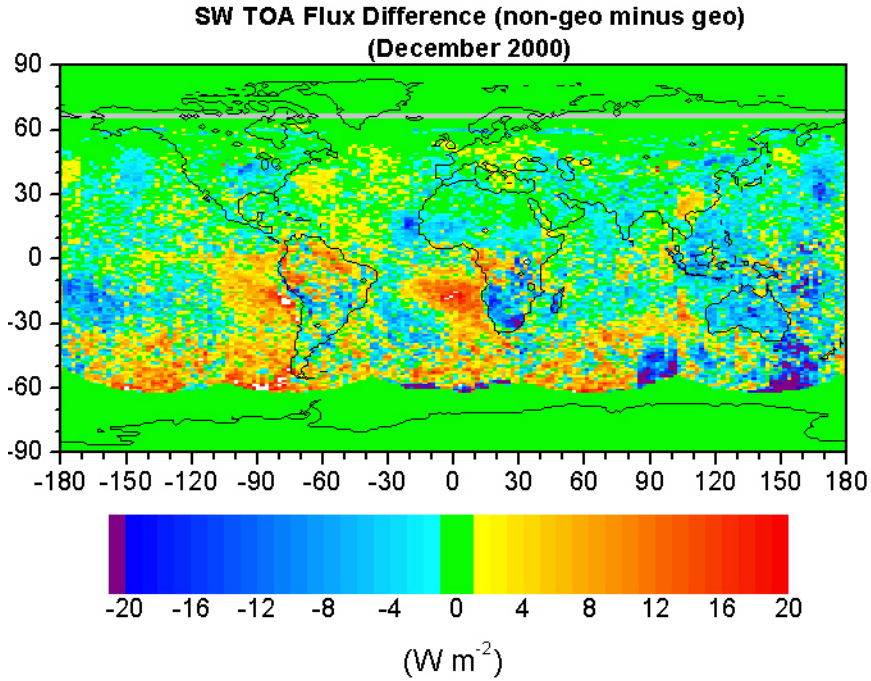

SW TOA Flux (with GEO)
(June 2000)
90
60
30
0
-30
-60
-90
-180 -150 -120 -90 -60 -30 0 30 60 90 120 150 180
0 50 100 150 200 250

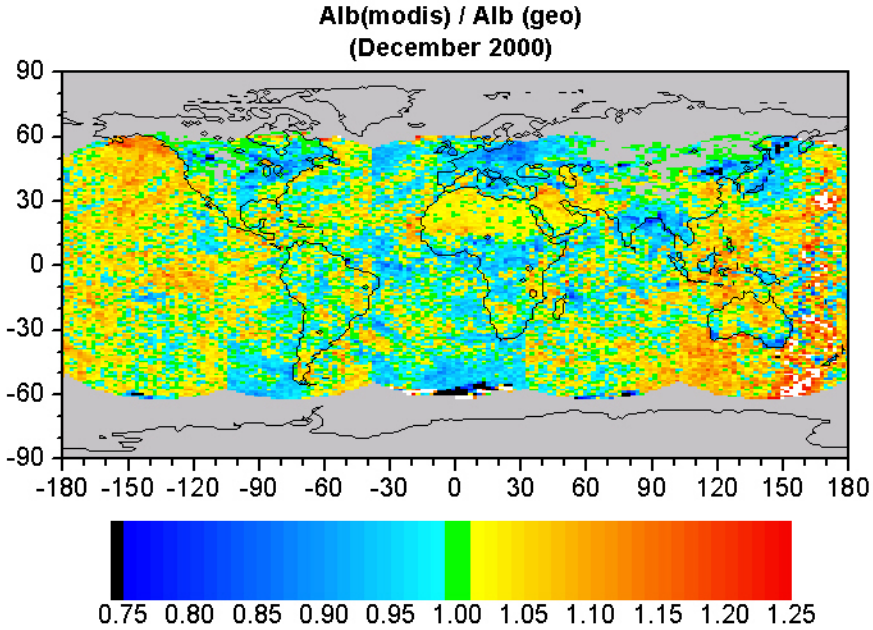

SW TOA Flux Difference (non-geo minus geo)
(June 2000)
90
60
30
0
-30
-60
-90
-180 -150 -120 -90 -60 -30 0 30 60 90 120 150 180
-20 -16 -12 -8 -4 0 4 8 12 16 20
(W m-2)

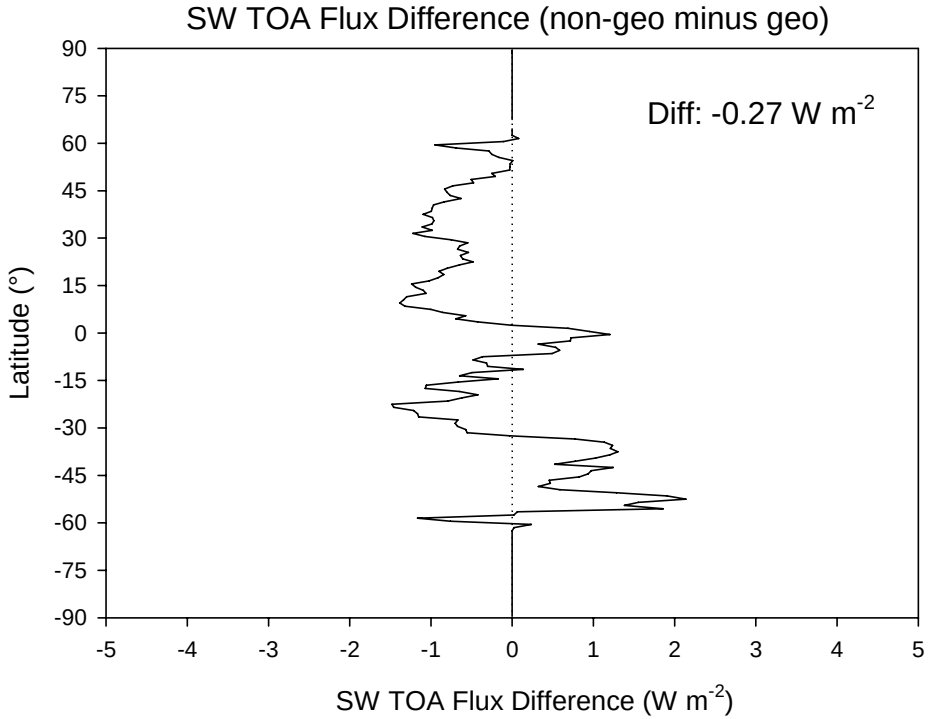

Alb(modis) / Alb (geo)
(June 2000)
90
60
30
0
-30
-60
-90
-180 -150 -120 -90 -60 -30 0 30 60 90 120 150 180
0.75 0.80 0.85 0.90 0.95 1.00 1.05 1.10 1.15 1.20 1.25


SW TOA Flux Difference (non-geo minus geo)
Diff: -0.82 W m-2
Latitude (°)
90
75
60
45
30
15
0
-15
-30
-45
-60
-75
-90
-5 -4 -3 -2 -1 0 1 2 3 4 5
SW TOA Flux Difference (W m-2)

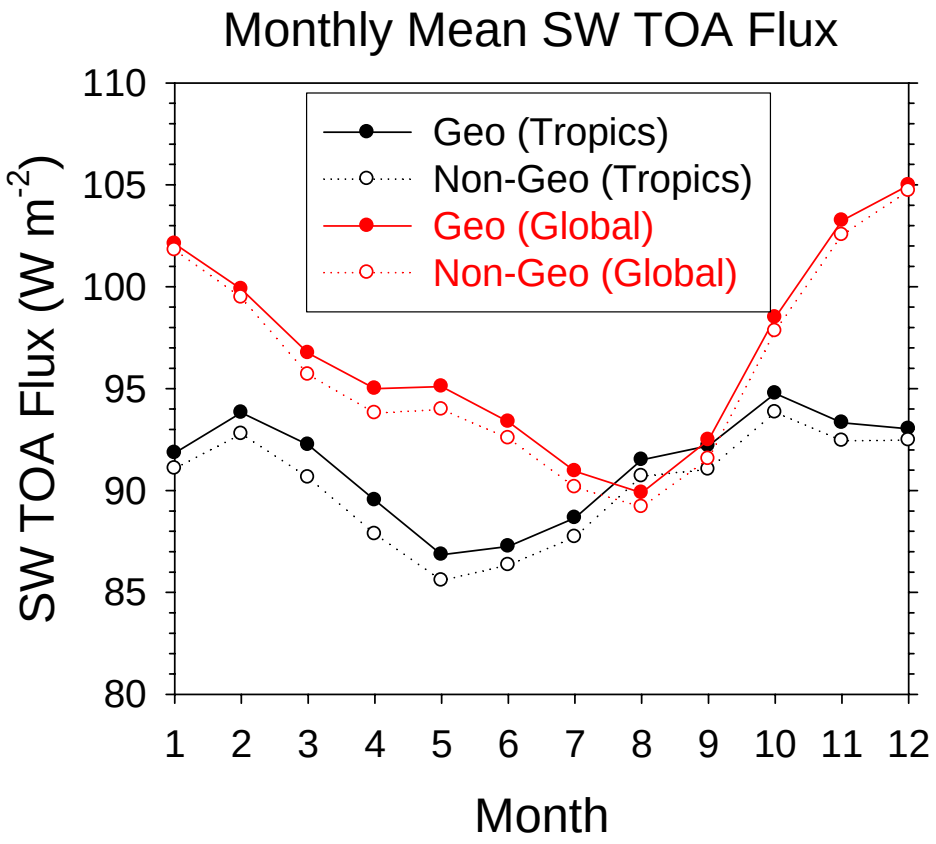

SW TOA Flux (with GEO)
(December 2000)
90
60
30
0
-30
-60
-90
-180 -150 -120 -90 -60 -30 0 30 60 90 120 150 180
0 50 100 150 200 250

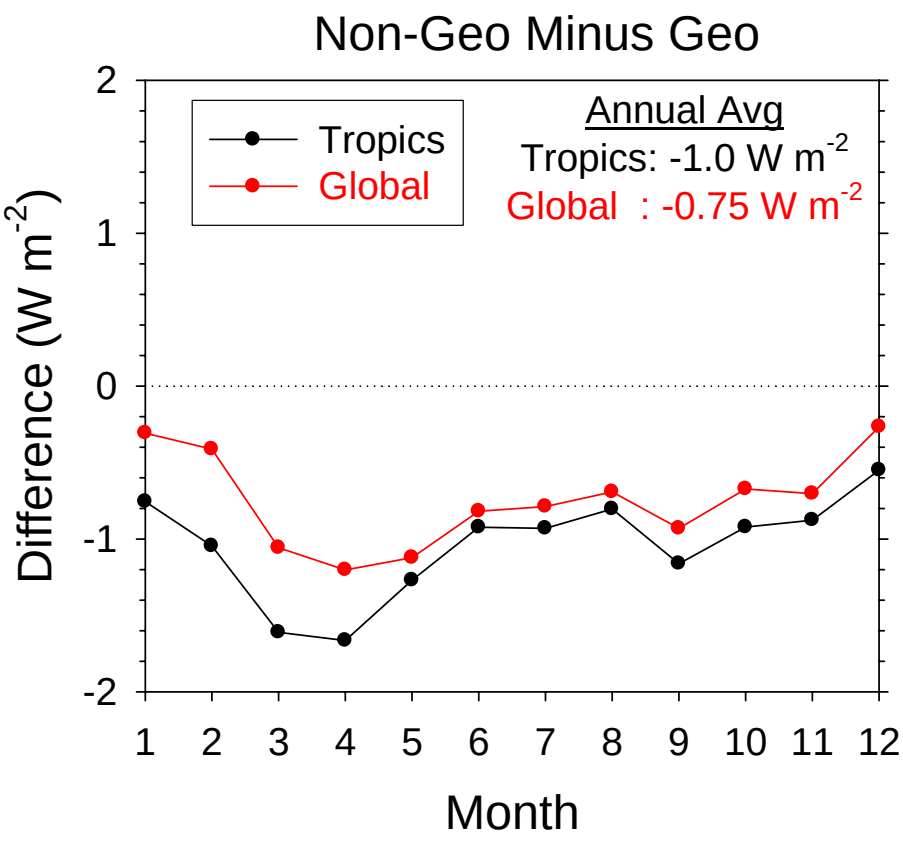

SW TOA Flux Difference (non-geo minus geo)
(December 2000)
90
60
30
0
-30
-60
-90
-180 -150 -120 -90 -60 -30 0 30 60 90 120 150 180
-20 -16 -12 -8 -4 0 4 8 12 16 20
(W m-2)

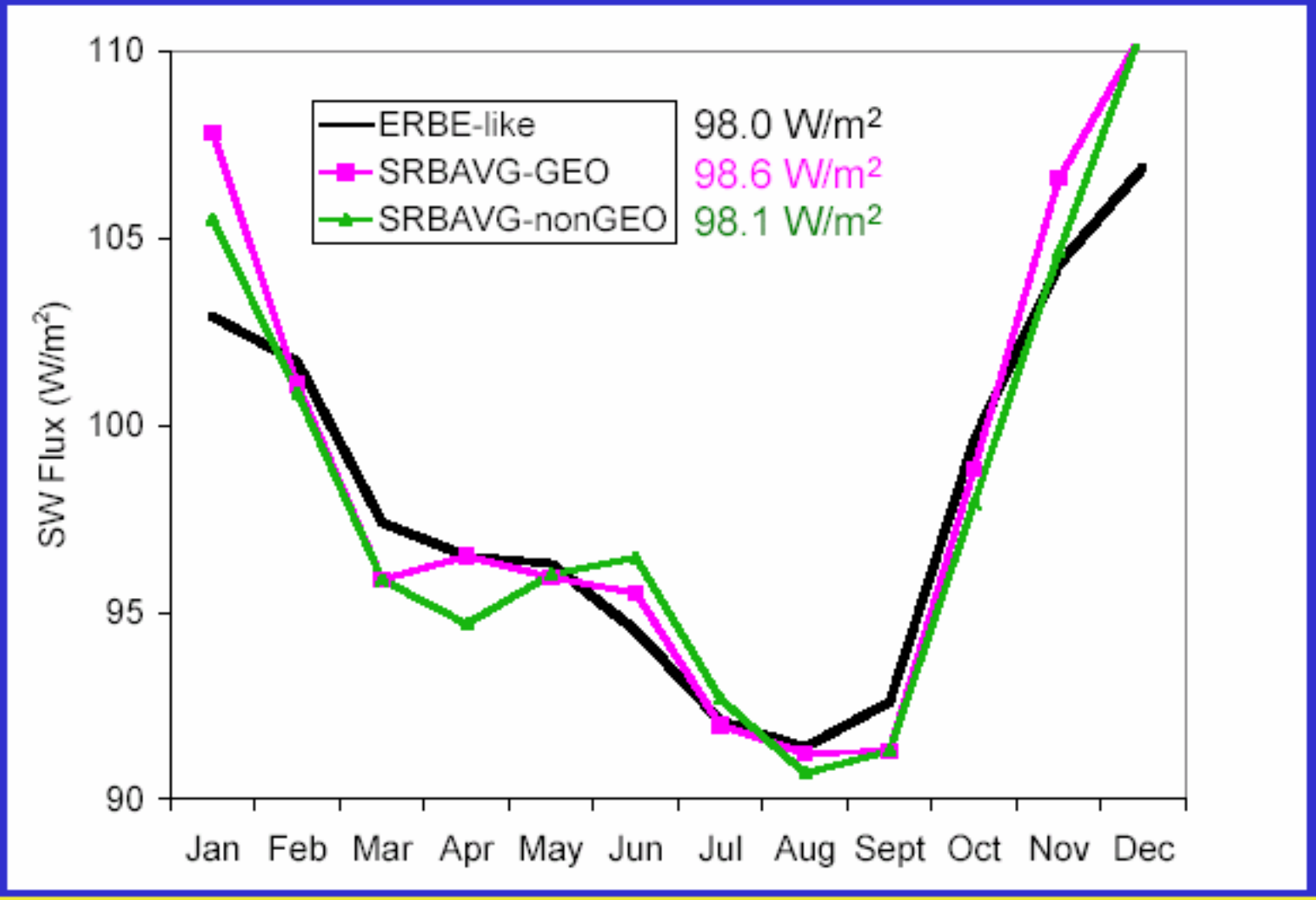

Alb(modis) / Alb (geo)
(December 2000)
90
60
30
0
-30
-60
-90
-180 -150 -120 -90 -60 -30 0 30 60 90 120 150 180
0.75 0.80 0.85 0.90 0.95 1.00 1.05 1.10 1.15 1.20 1.25


SW TOA Flux Difference (non-geo minus geo)
Diff: -0.27 W m-2
Latitude (°)
90
75
60
45
30
15
0
-15
-30
-45
-60
-75
-90
-5 -4 -3 -2 -1 0 1 2 3 4 5
SW TOA Flux Difference (W m-2)

Global SW TOA Flux Comparison: Non-Geo vs GEO (2000)





Global TOA SW Flux Comparison

Beta 2 SRBAVG January-December 2001