TOA Radiative Flux Estimation From CERES Angular Distribution Models

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May 6, 2003

TOA Flux Group Activities

Sept 2002 – May 2003

ADM Publications:

i) ADM paper (Part I) describing CERES/TRMM SW, LW & WN ADMs (*J. Appl. Meteor., 42, 240-265,* 2003).

ii) Part II summarizing TRMM ADM validation results (accepted with minor revisions).

iii) Paper on use of neural networks for TOA flux estimation - (Konstantin Loukachine; accepted with minor revisions).

iv) Paper comparing theoretical and empirical retrievals of TOA albedo from ice clouds using POLDER data (Wenbo Sun; in preparation).

May 2003 – Sept 2003

Development and validation of Terra ADMs based on 2 years of CERES/Terra RAP measurements.

Terra ADM Development

- Terra ADMs will be based on 2 years of CERES measurements.
- Increase angular resolution of ADMs (goal: 2° or 5°).
- Increase the number of scene types.
- Testing new 1°-resolution clear land+desert ADMs.
- New Snow and sea-ice ADMs.
- Use of “continuous” LW ADM scene types.
- Neural network scheme to improve TOA flux estimates for footprints with excessive “no retrievals”.
- Validation: Extend alongtrack instantaneous TOA flux consistency tests.

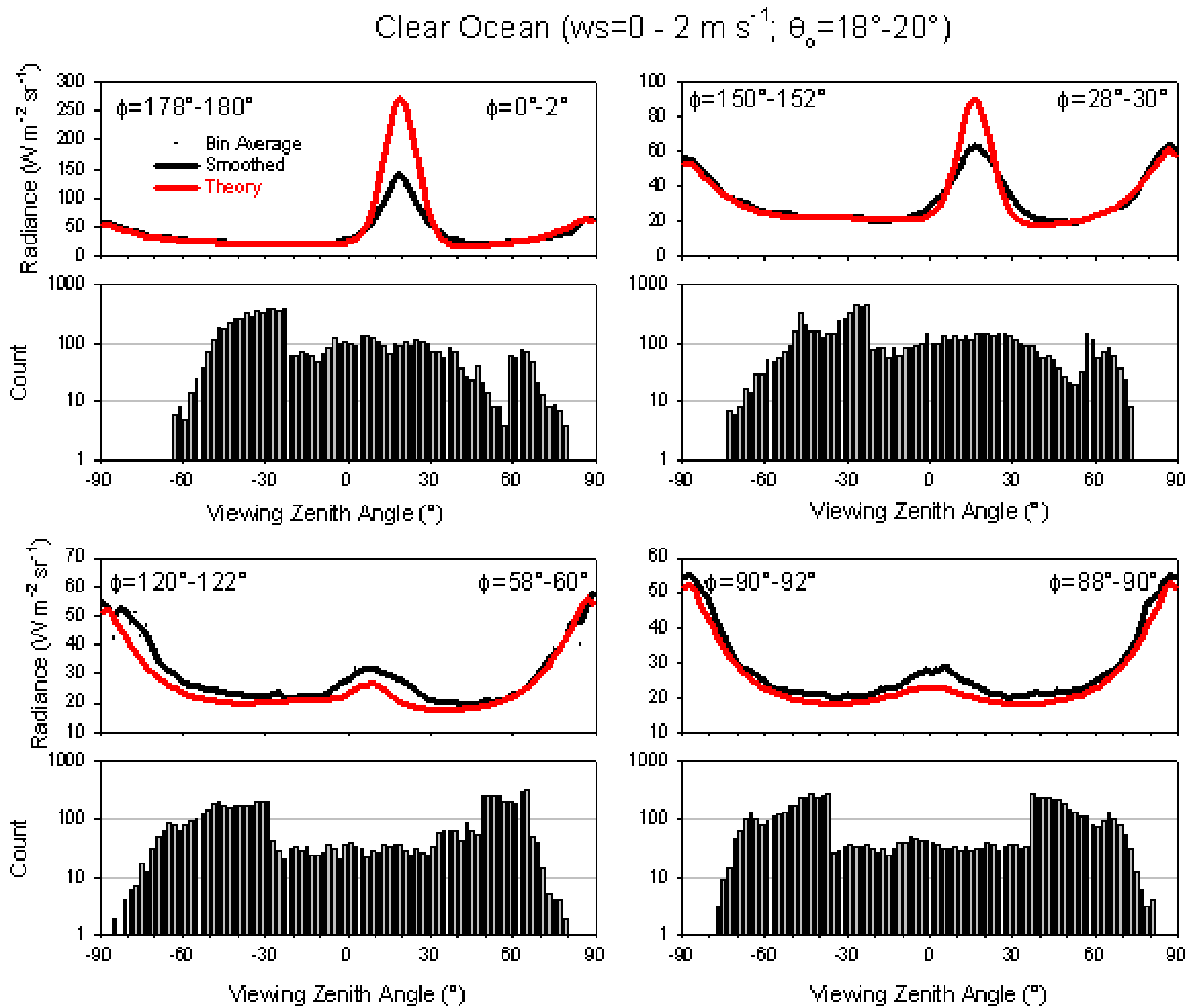
Terra SW ADMs – Clear Ocean

Terra SW ADMs – Clear Scenes

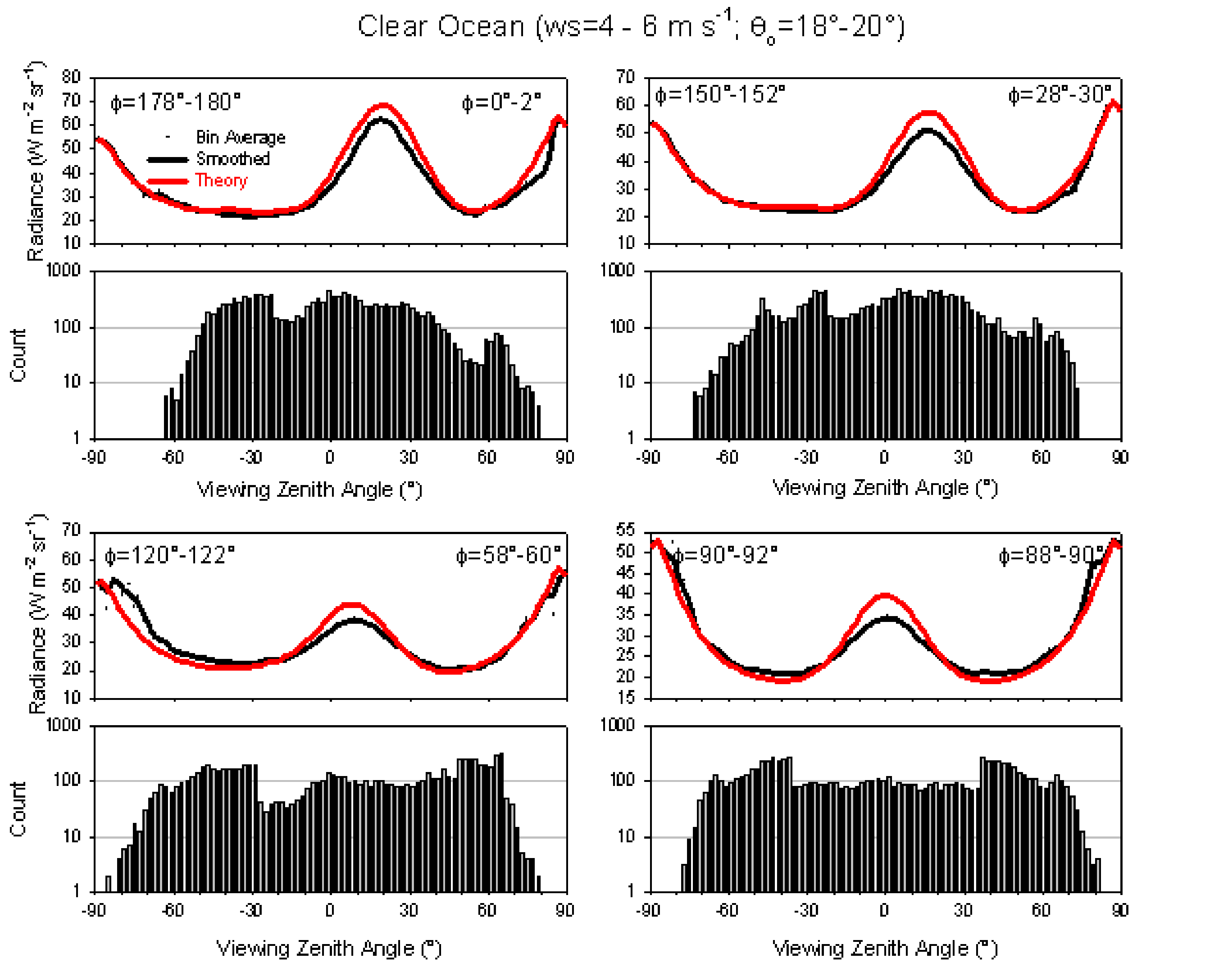
Clear Ocean:

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

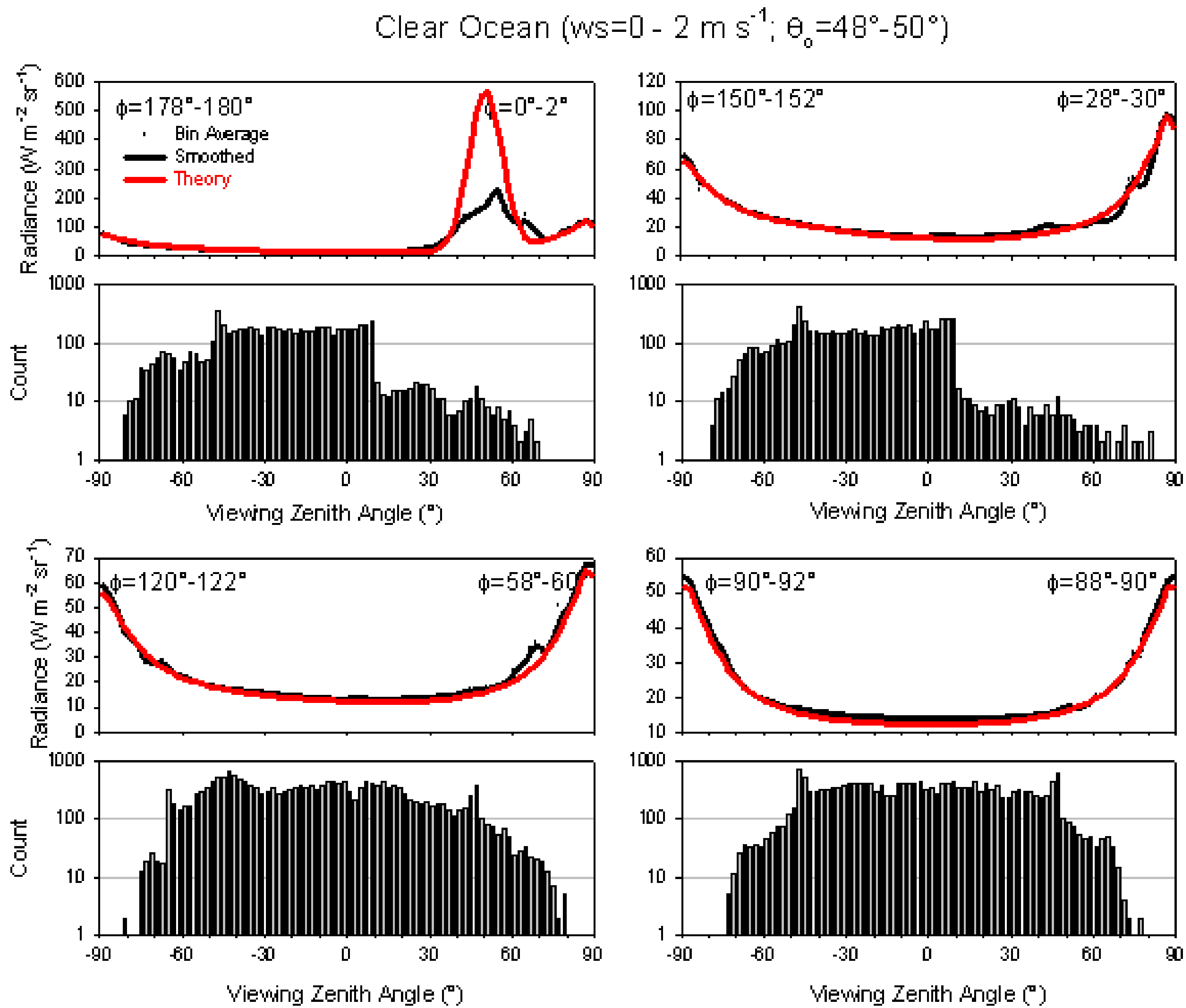
* 6 bins of wind speed (0-12 $m\ s^{-1}$ in steps of 2 $m\ s^{-1}$)
* 45 solar zenith angle bins (0-90 deg in steps of 2 deg)
* 45 viewing zenith angle bins (0-90 deg in steps of 2 deg)
* 90 relative azimuth angle bins (0-180 deg in steps of 2 deg)



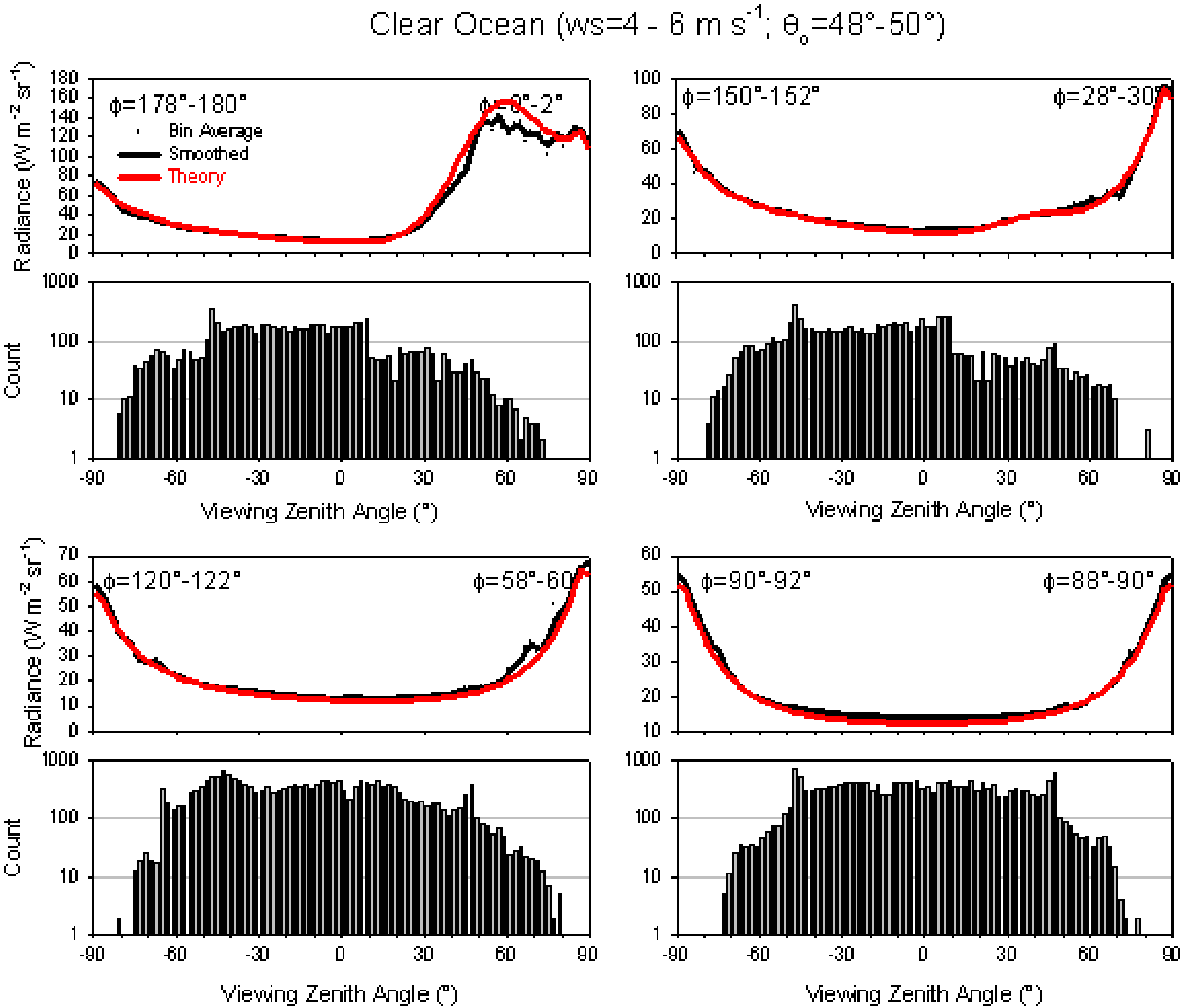
Clear Ocean (ws=0 - 2 m s^{-1}; θ$_o$=18°-20°)
φ=178°-180°
φ=0°-2°
Bin Average
Smoothed
Theory
Radiance (W m^{-2} sr^{-1})
Count
Viewing Zenith Angle (°)
φ=150°-152°
φ=28°-30°
φ=120°-122°
φ=58°-60°
φ=90°-92°
φ=88°-90°



Clear Ocean (ws=4 - 6 m s-1; θo=18°-20°)
Radiance (W m-2 sr-1)
Count
Viewing Zenith Angle (°)
φ=178°-180°
φ=0°-2°
Bin Average
Smoothed
Theory
φ=150°-152°
φ=28°-30°
φ=120°-122°
φ=58°-60°
φ=90°-92°
φ=88°-90°



Clear Ocean (ws=0 - 2 m s^{-1}; θ$_o$=48°-50°)
φ=178°-180°
φ=0°-2°
Bin Average
Smoothed
Theory
Radiance (W m^{-2} sr^{-1})
Count
Viewing Zenith Angle (°)
φ=150°-152°
φ=28°-30°
φ=120°-122°
φ=58°-60°
φ=90°-92°
φ=88°-90°

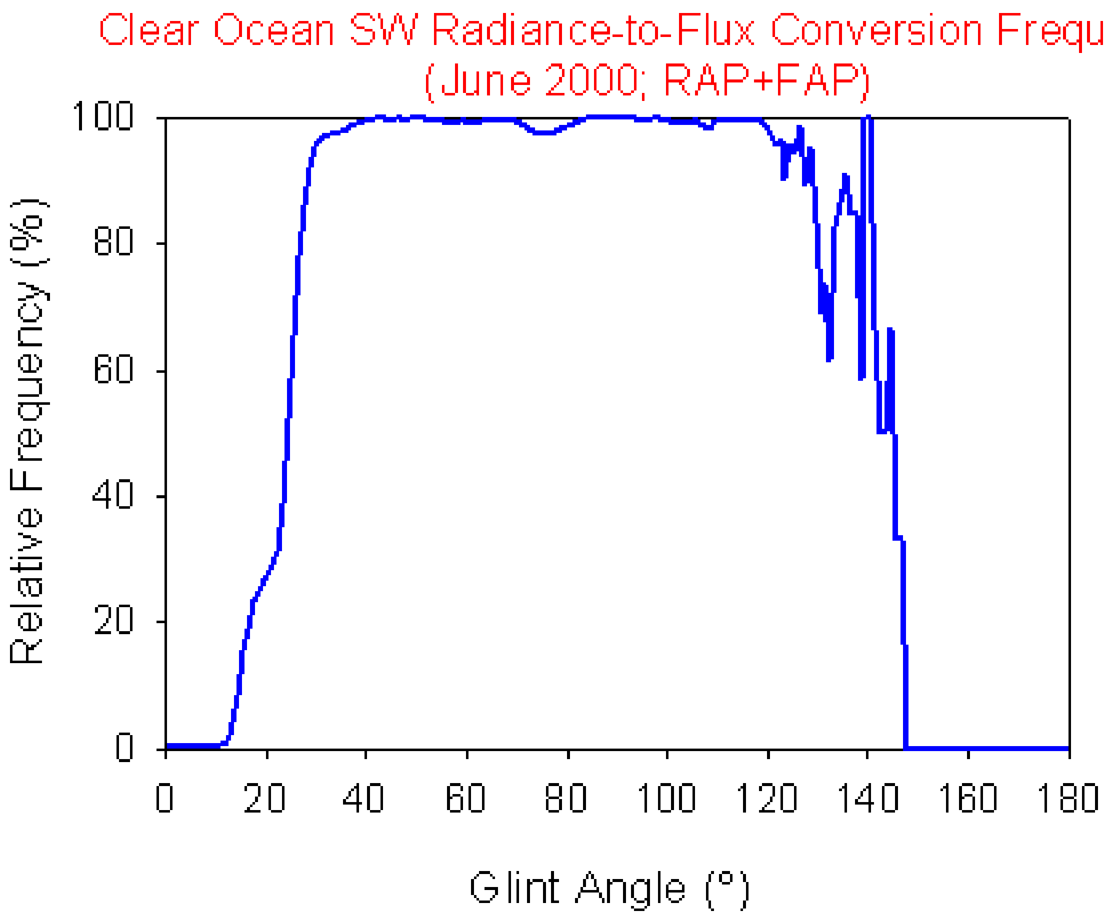


Clear Ocean (ws=4 - 6 m s^-1; θo=48°-50°)
φ=178°-180°
φ=0°-2°
Bin Average
Smoothed
Theory
Radiance (W m^-2 sr^-1)
Count
φ=150°-152°
φ=28°-30°
φ=120°-122°
φ=58°-60°
φ=90°-92°
φ=88°-90°
Viewing Zenith Angle (°)

Glint avoidance?

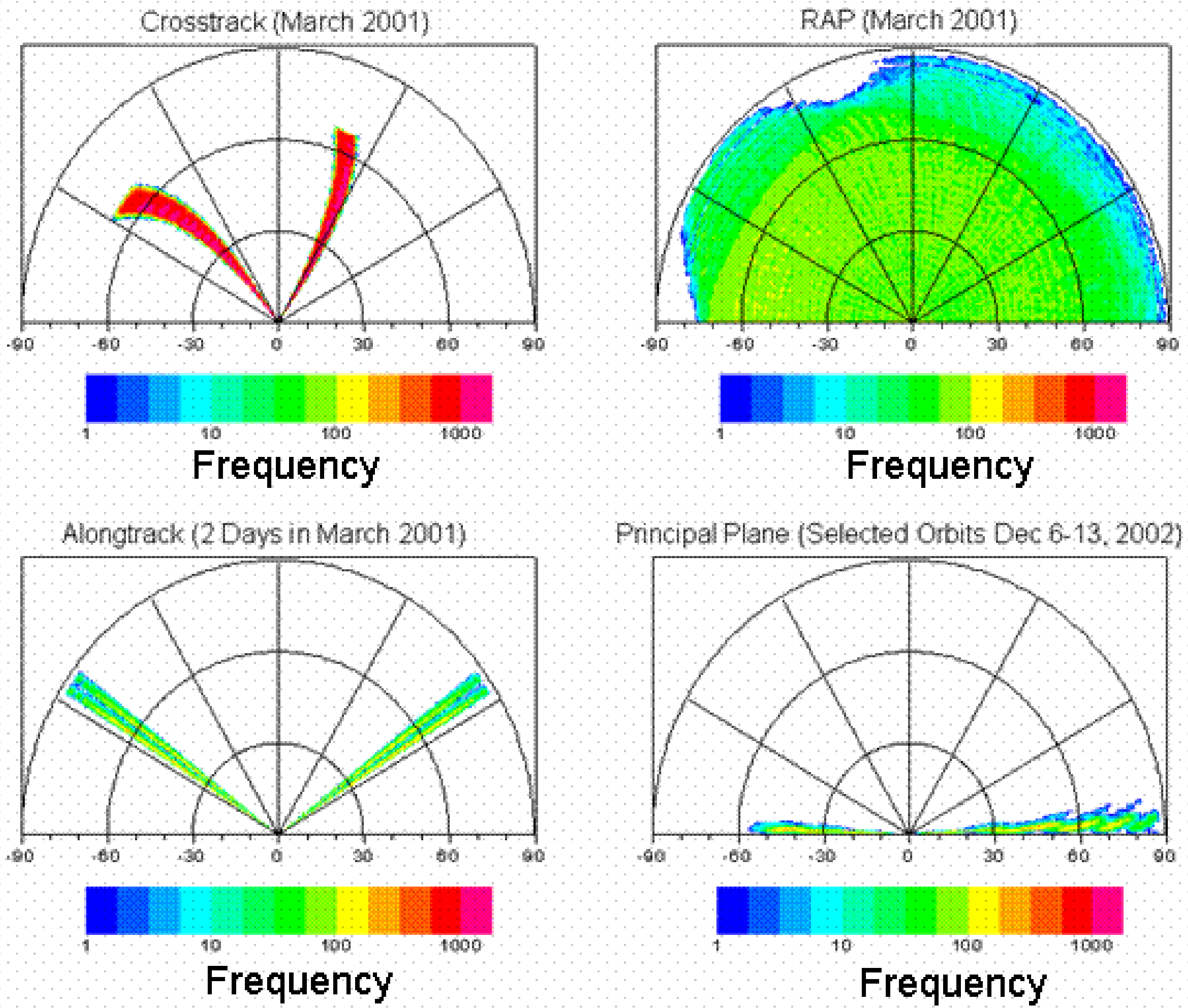
To determine whether or not to perform a retrieval for a given measurement, the standard deviation of the ADM anisotropic factors in the vicinity of the measurement (i.e. surrounding w_s, θ_o, θ, and ϕ bins) must be less than 0.05.

Otherwise, use ADM mean flux value as default.

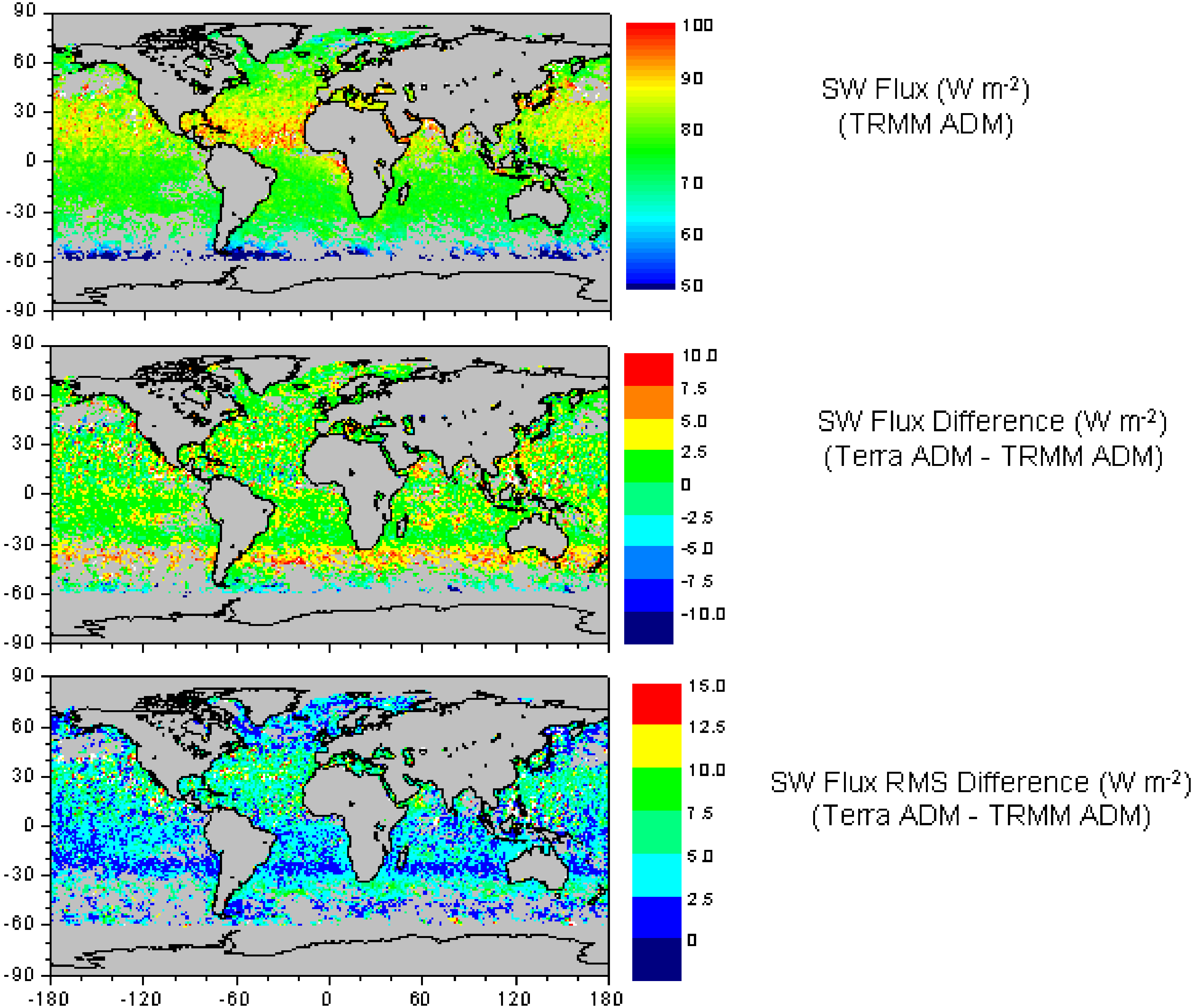


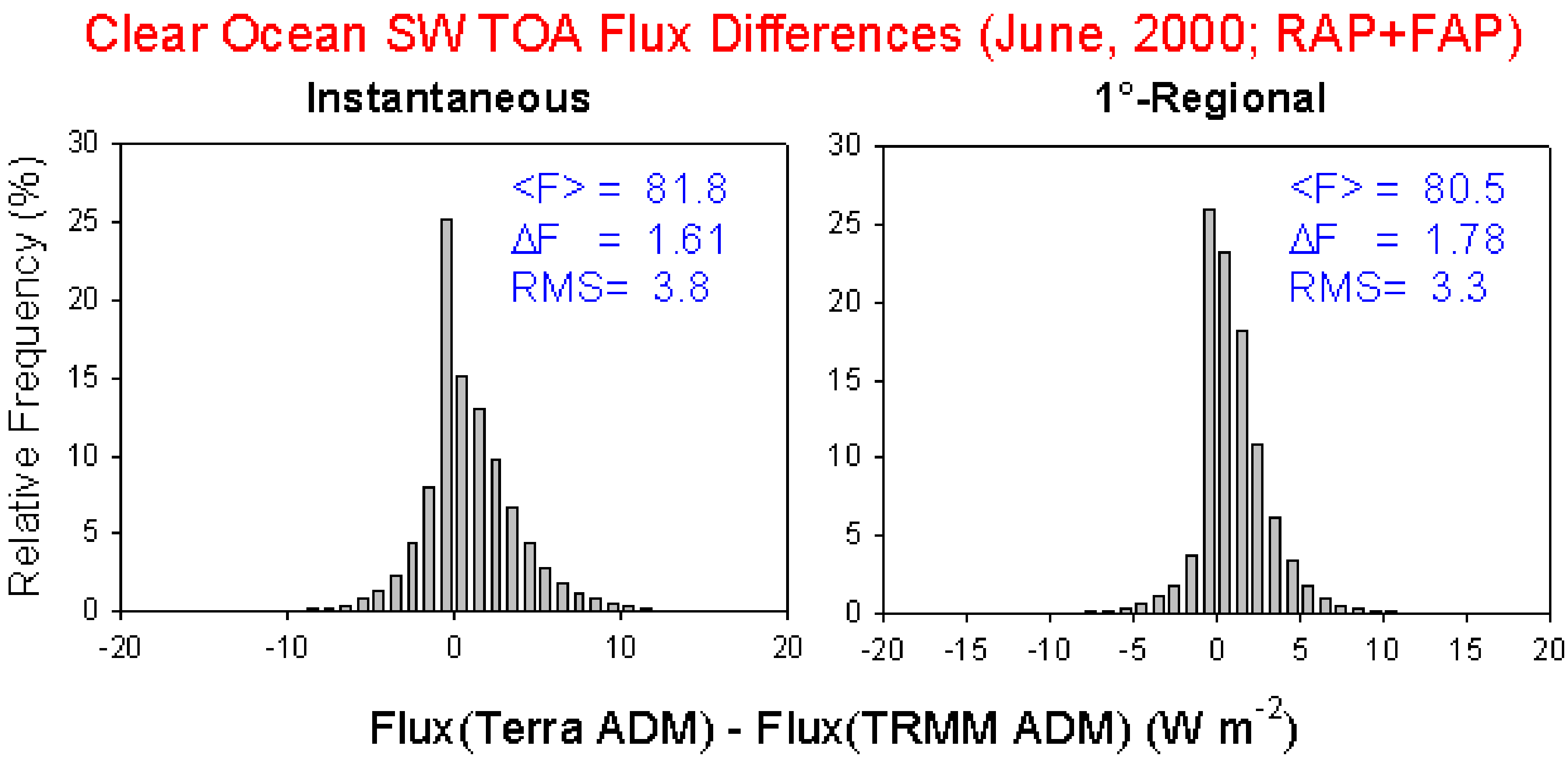
- 74% of all clear FOVs inverted
- Otherwise use ADM Direct Integration value

Sampling For Different CERES Scan Modes (θ_0=40°-41°)



Clear-Sky Ocean SW TOA Flux: Terra, June 2000 (RAP+FAP)

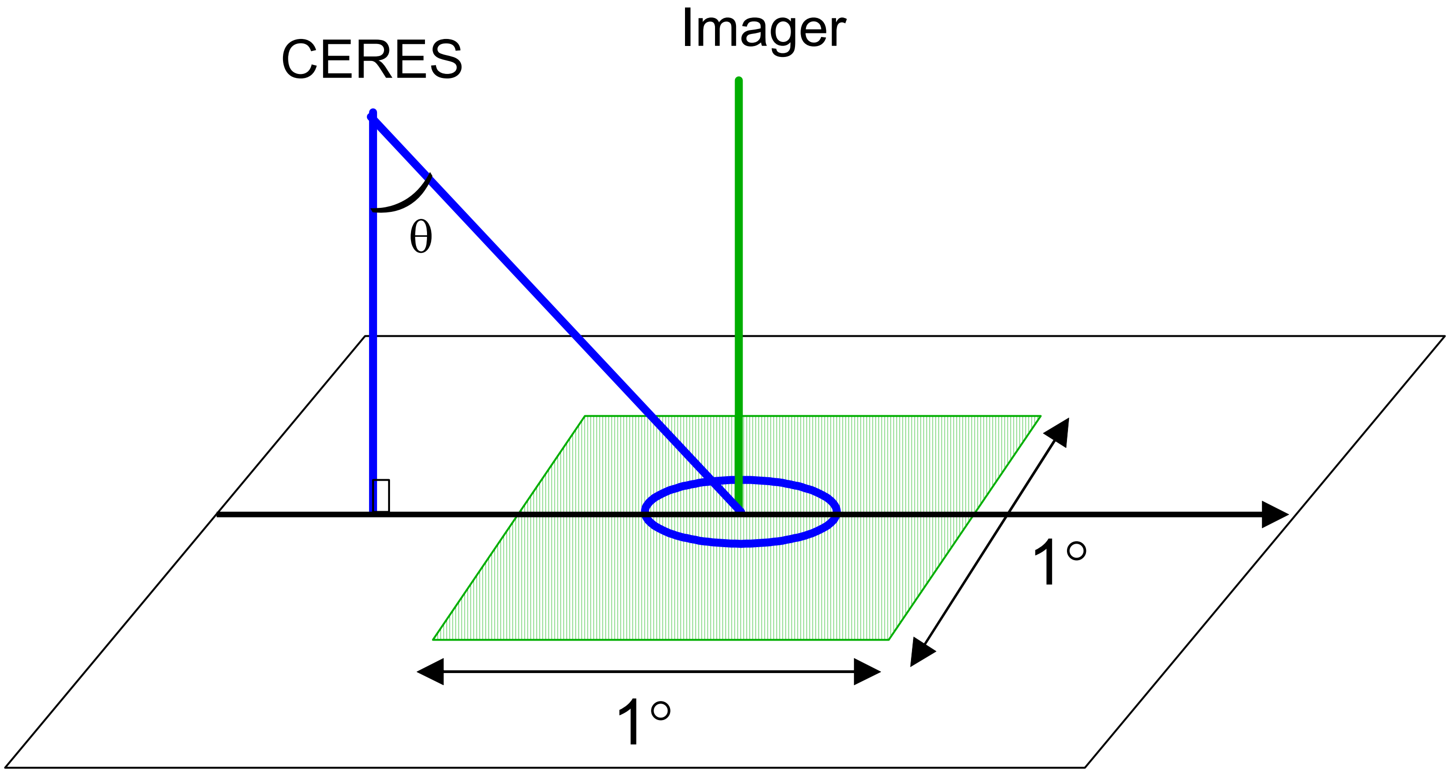




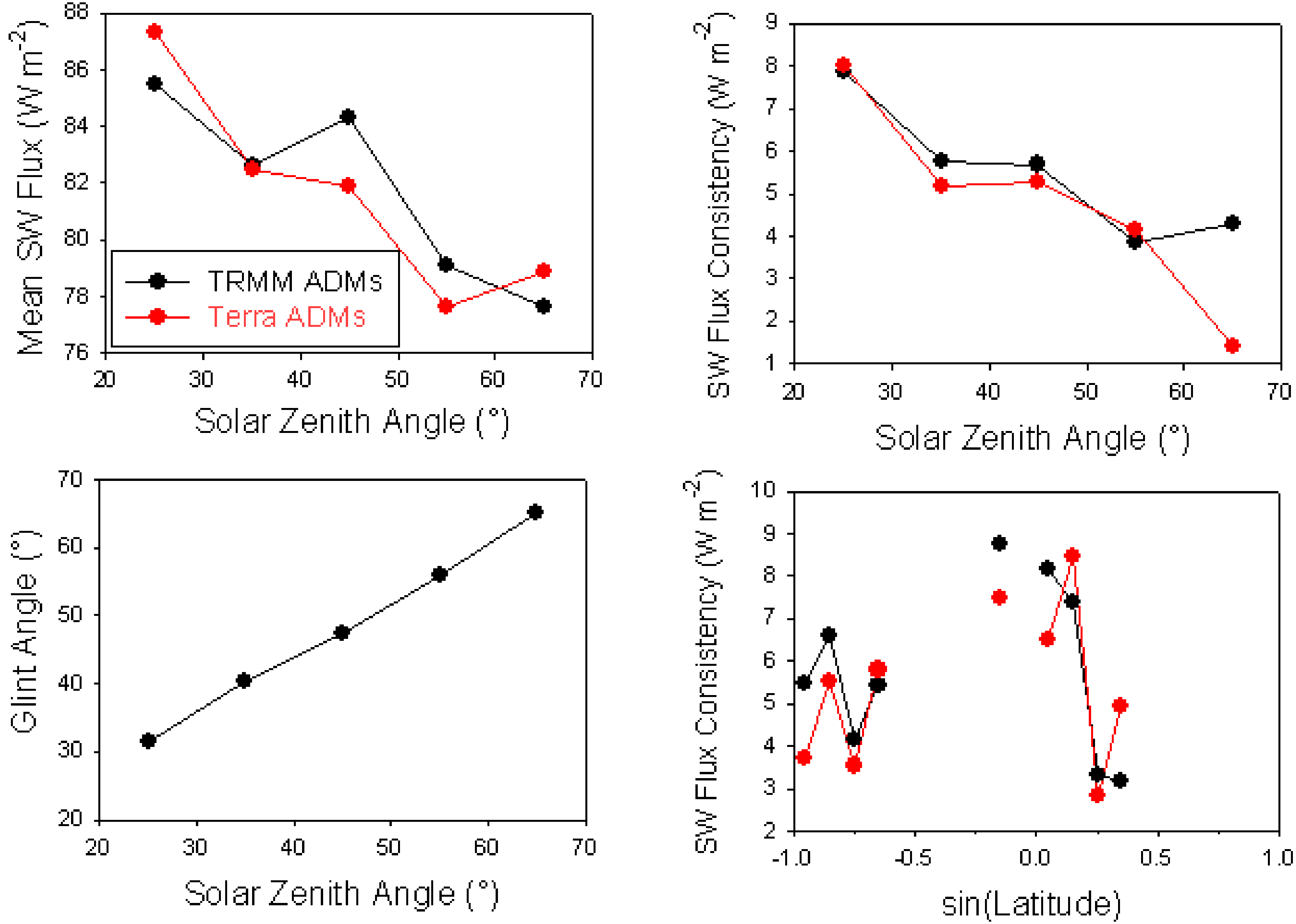
Clear Ocean SW TOA Flux Differences (June, 2000; RAP+FAP)
Instantaneous
1°-Regional
Relative Frequency (%)
<F> = 81.8
ΔF = 1.61
RMS= 3.8
<F> = 80.5
ΔF = 1.78
RMS= 3.3
0
5
10
15
20
25
30
-20
-15
-10
-5
0
5
10
15
20
Flux(Terra ADM) - Flux(TRMM ADM) (W m-2)

1° Regional Instantaneous TOA Flux Consistency Test

Objective: Compare ADM-derived TOA fluxes over 1° regions from different viewing geometries. Are TOA fluxes consistent?



Instantaneous SW TOA Flux Consistency Tests: 1° Regions
(F(Nadir) vs F(60° < θ ≤ 70°); November to April, 2000, 2001)
Clear Ocean



Terra SW ADMs – Clouds Over Ocean

Terra SW ADMs – Clouds Over Ocean

Clouds over Ocean:

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

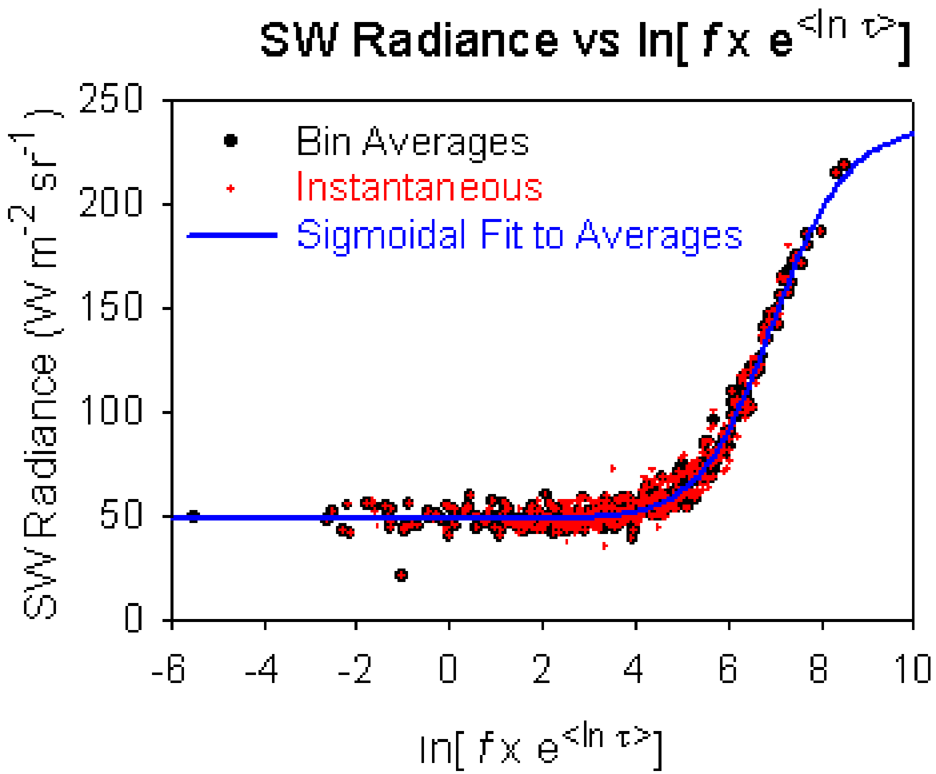
i) Liquid Water (Phase < 1.01)

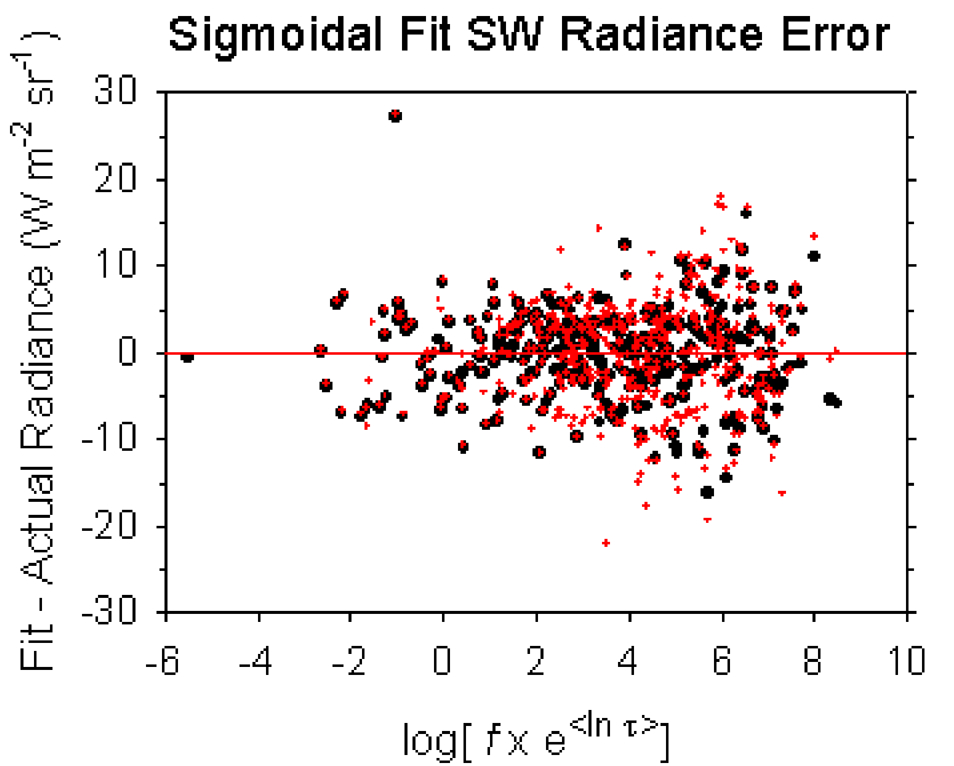
ii) Mixed Phase ($1.01 \leq$ Phase ≤ 1.75)

iii) Ice (Phase > 1.75)

Uncertainties in Sigmoidal SW Radiance Fits

(Liquid Water Clouds; θ_0=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

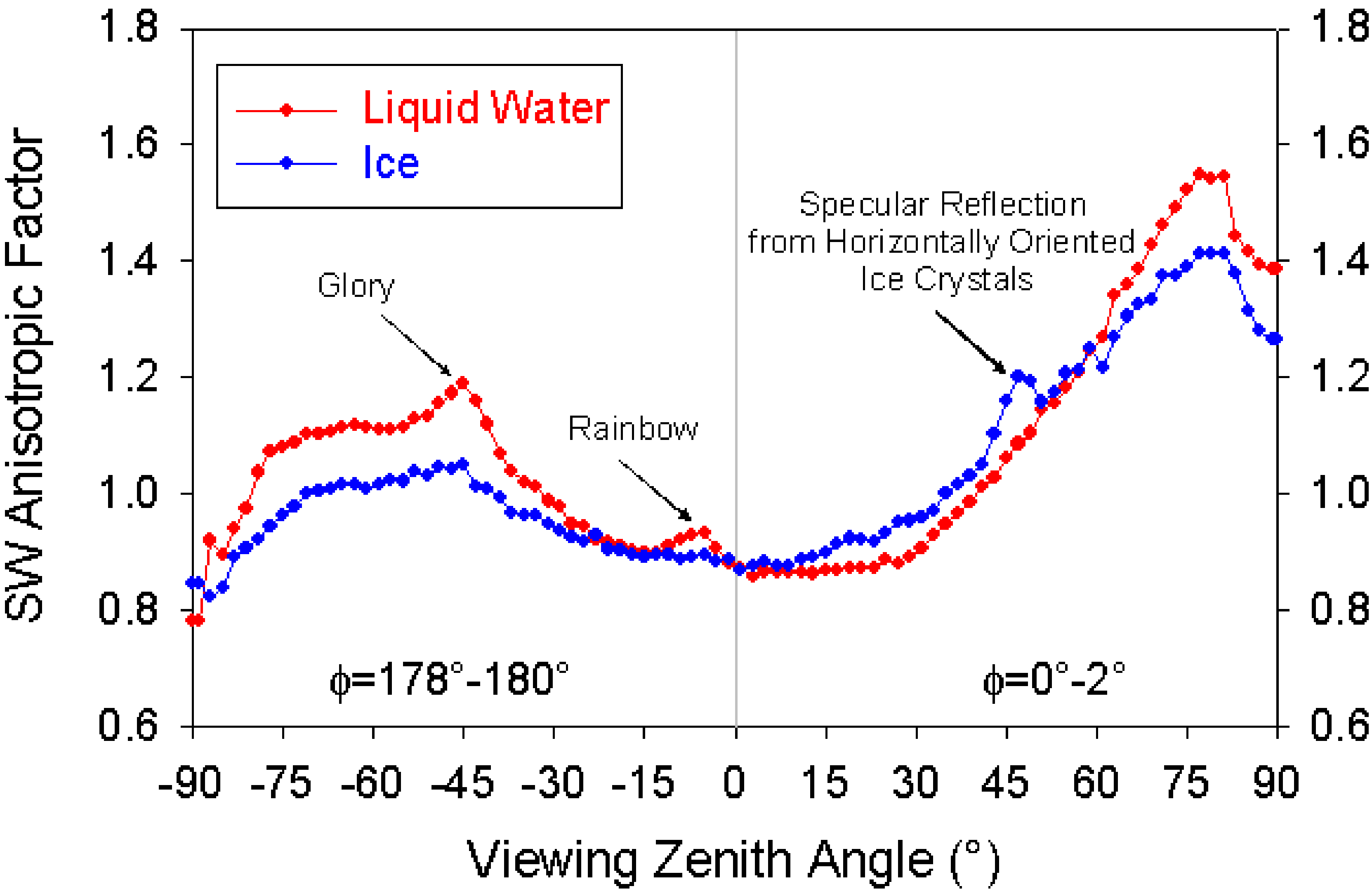
$$I = I_o + \frac{a}{\left[1 + e^{-\left(\frac{x - x_o}{b}\right)}\right]^c}$$

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

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

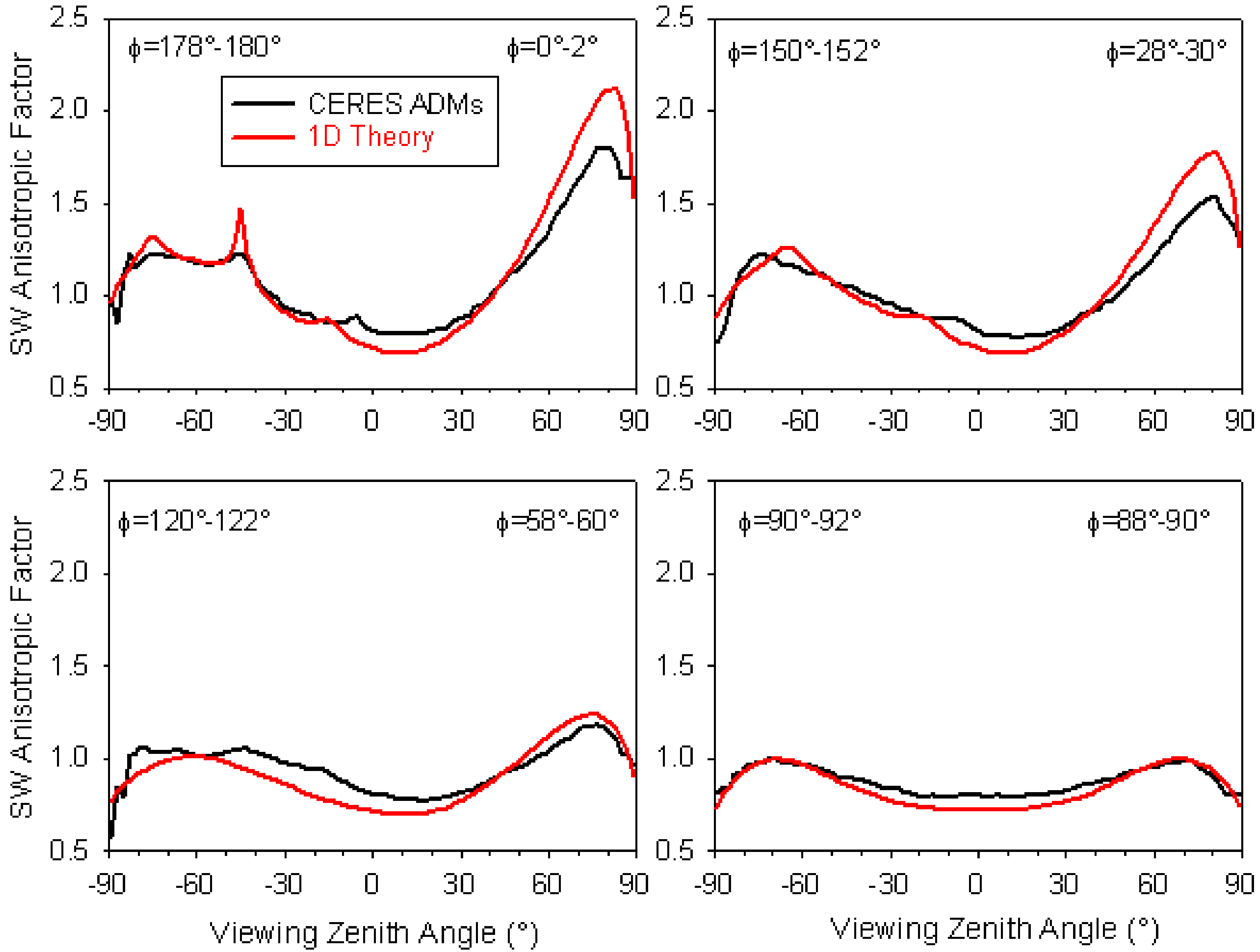
CERES/Terra ADM Anisotropic Factors in the Principal Plane

(θ_0=44°-46°; Ocean; $f\,e^{<\ln\tau>}$ = 7.5; November 2000 - August 2001)



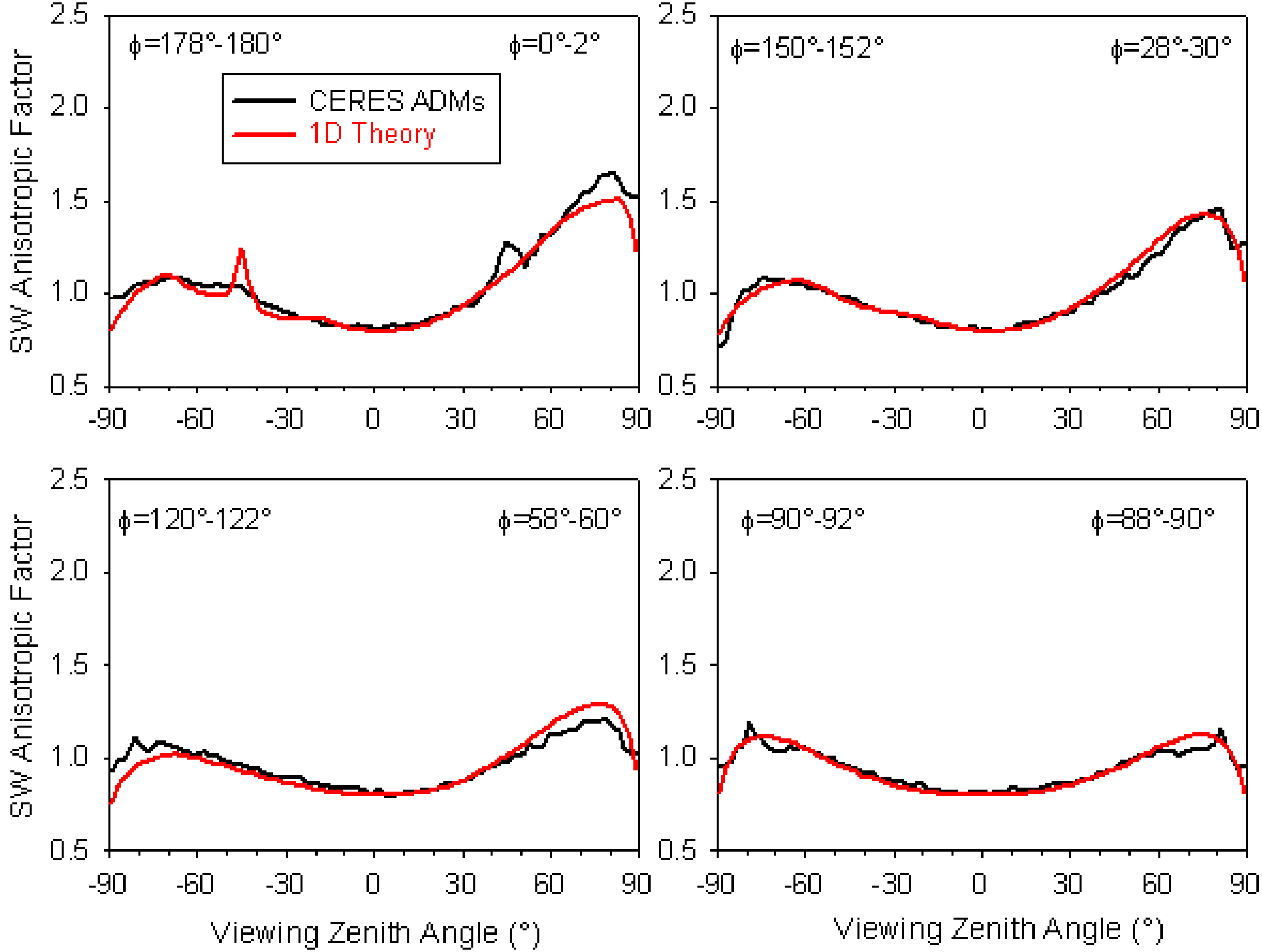
CERES/Terra ADM Anisotropic Factors

(Liquid Water Clouds; Ocean; θ_0=44°-46°; $f\,e^{<\ln\tau>}$ = 5)



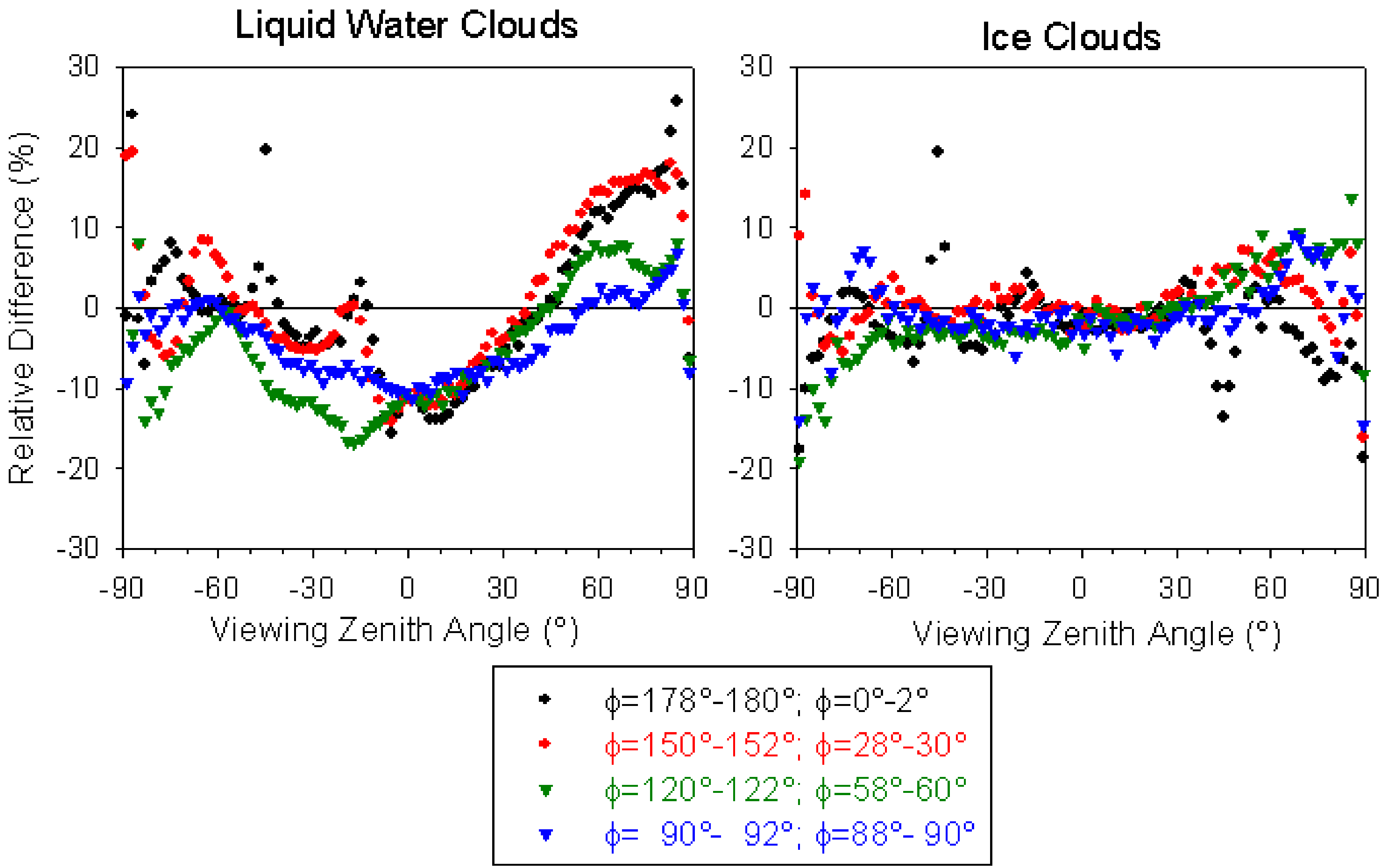
CERES/Terra ADM Anisotropic Factors

(Ice Clouds; Ocean; θ_0=44°-46°; $f\, e^{<\ln\tau>}$ = 5)

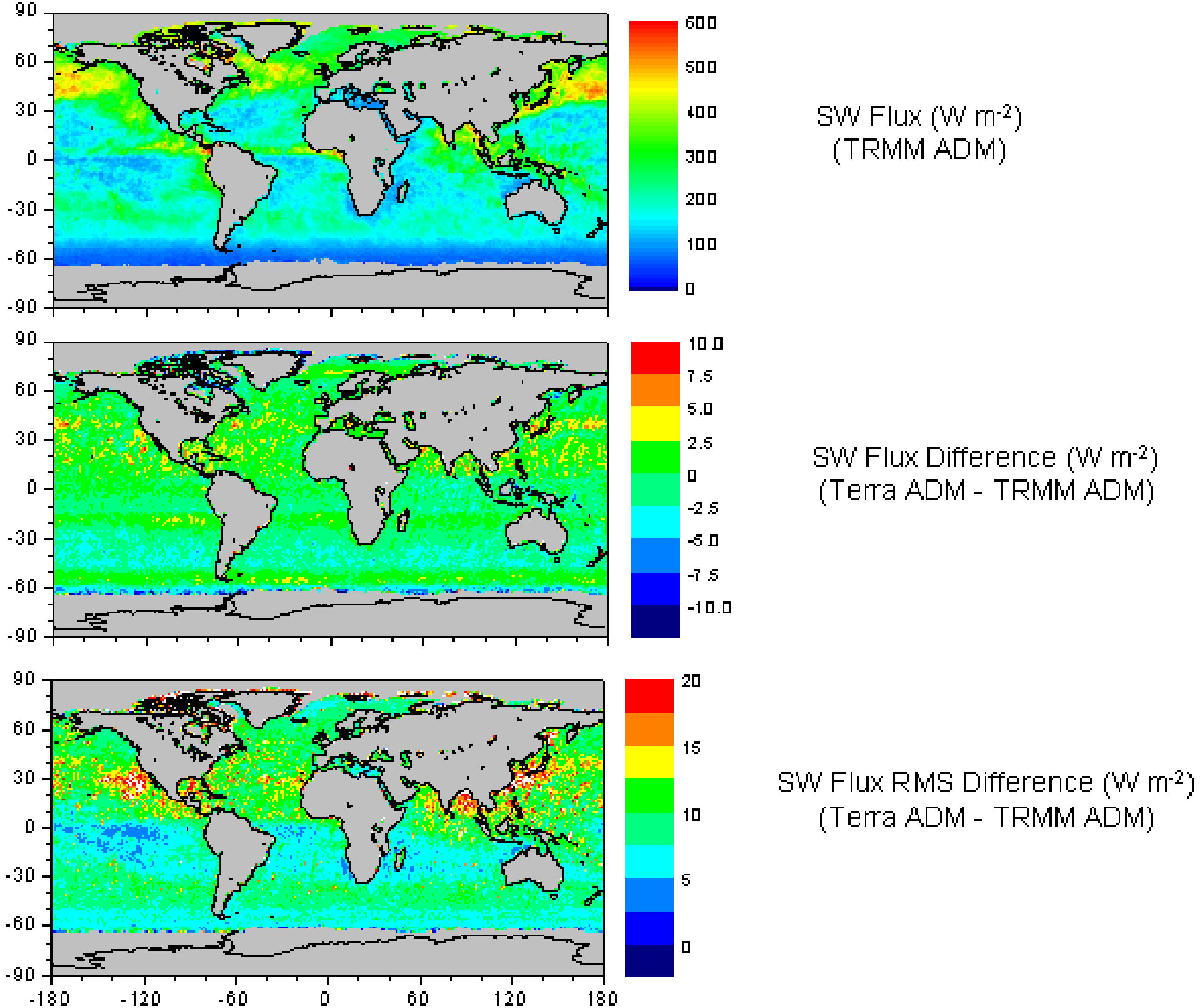


Theory vs CERES SW ADMs

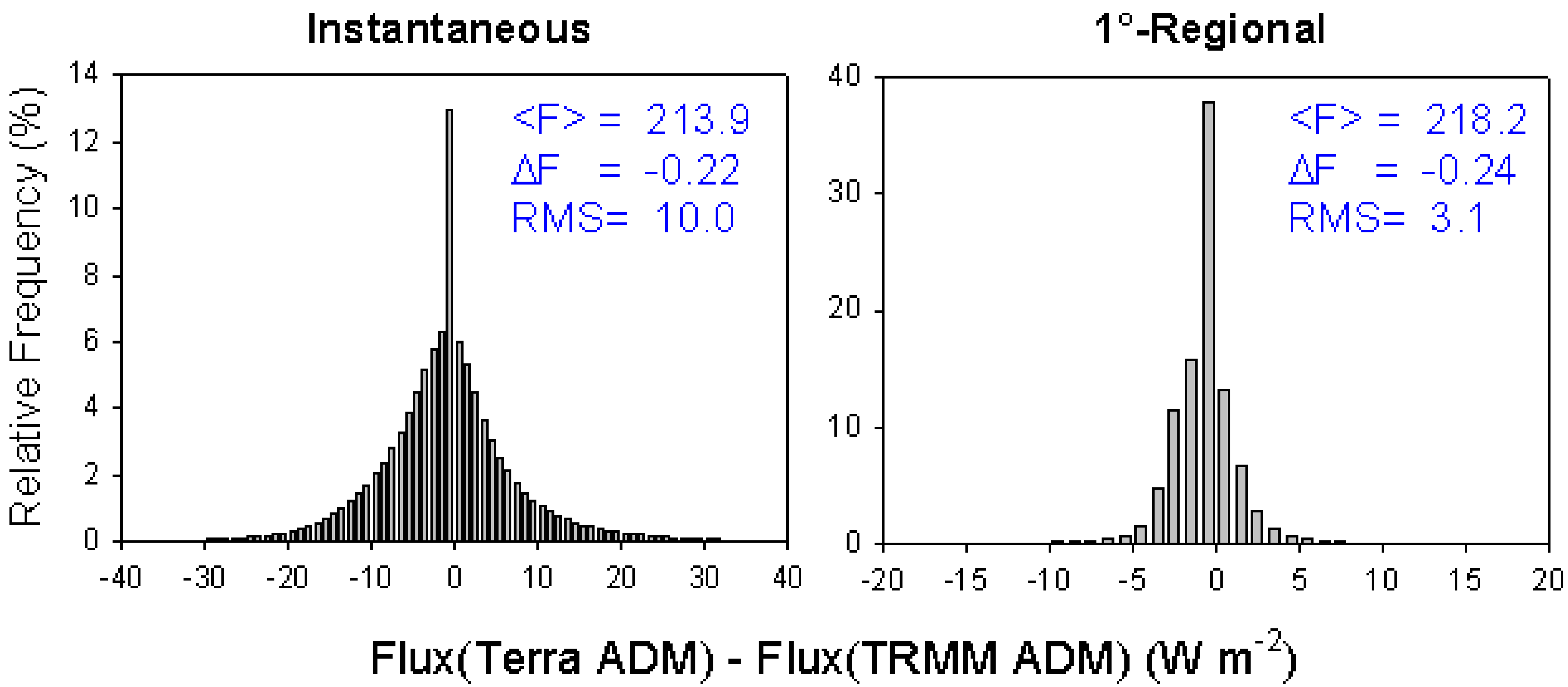
(Ocean; θ_0=44°-46°; $f\,e^{<\ln\tau>}$ = 5)



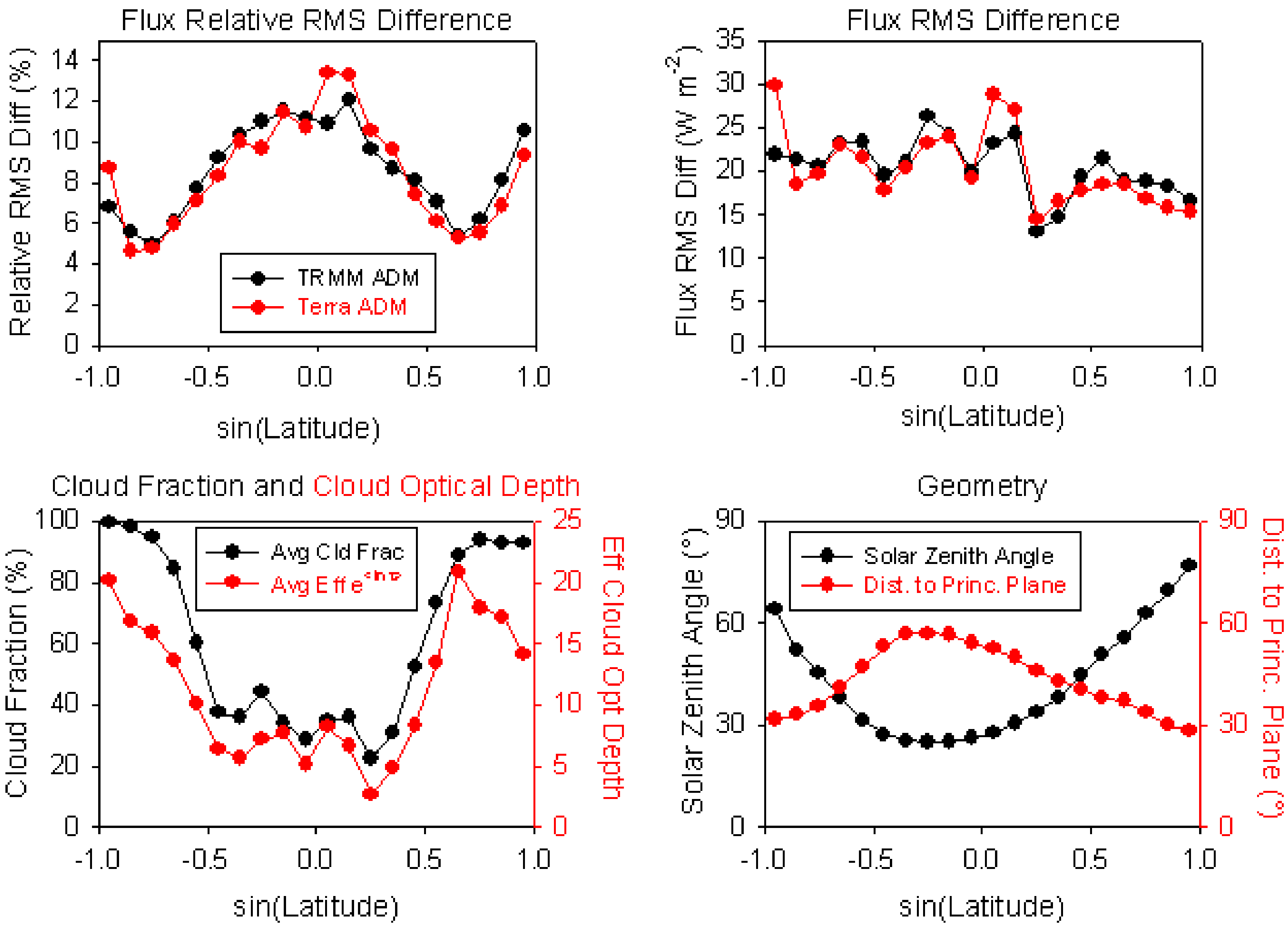
All-Sky Ocean SW TOA Flux: Terra, June 2000 (RAP+FAP)



All-Sky Ocean SW TOA Flux Differences (June, 2000; RAP+FAP)



All-Sky Ocean Instantaneous SW TOA Flux Consistency Tests: 1° Regions
(F(Nadir) vs F(60° < θ ≤ 70°); November to April, 2000, 2001)



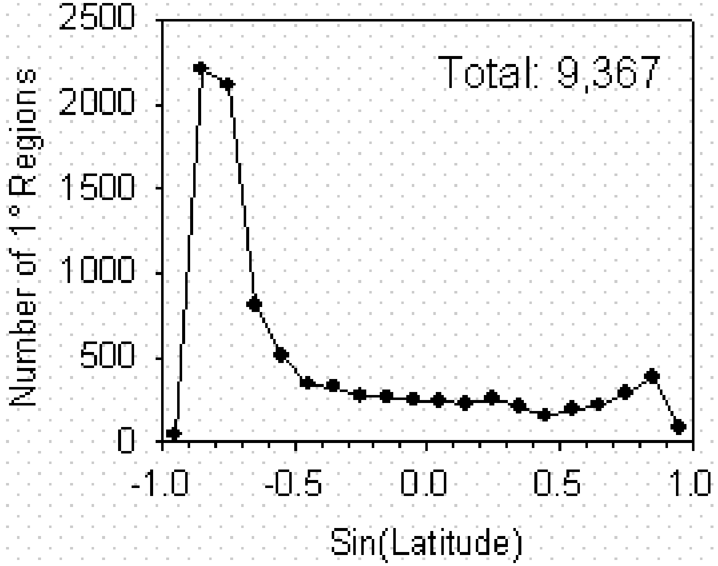
Instantaneous TOA Flux Consistency by "Cloud Type"

Separate 1°-regions comprised of CERES FOVs that are:

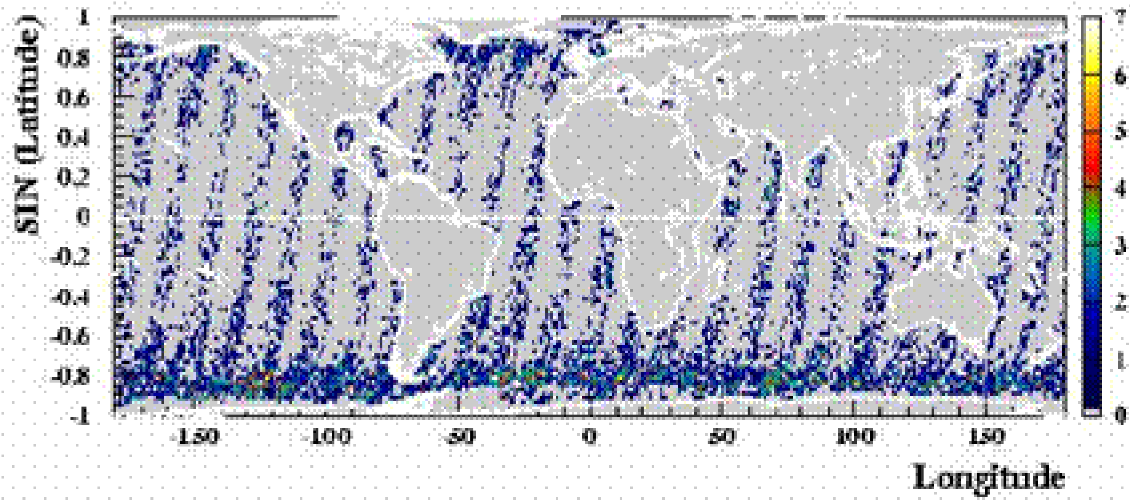
1. Single Layer Water (Overcast)
2. Single Layer Water ($f \leq 50\%$)
3. Single Layer Water ($f > 50\%$)
4. Single Layer Ice ($e^{<\ln\tau>} < 10$)
5. Single Layer Ice ($10 \leq e^{<\ln\tau>} \leq 50$)
6. Single Layer Ice ($e^{<\ln\tau>} > 50$)
7. Single Layer Mixed
8. Multilayer

Frequency of 1 Regions by Latitude and "Cloud Type"

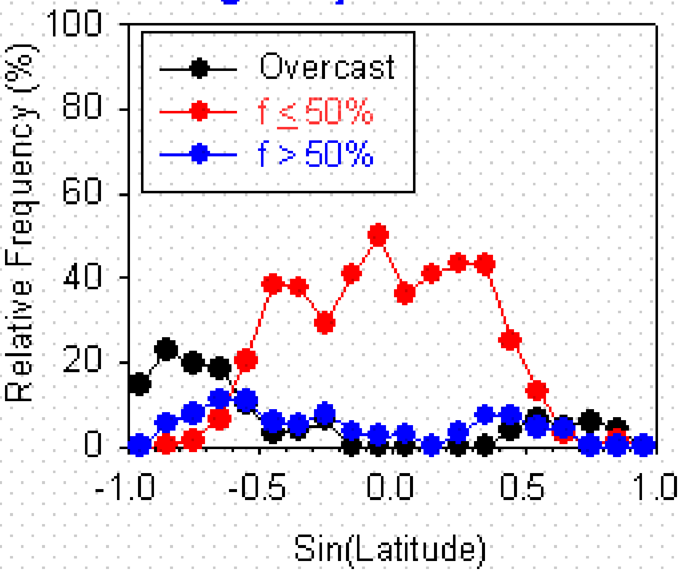
Number of 1° Regions by Latitude



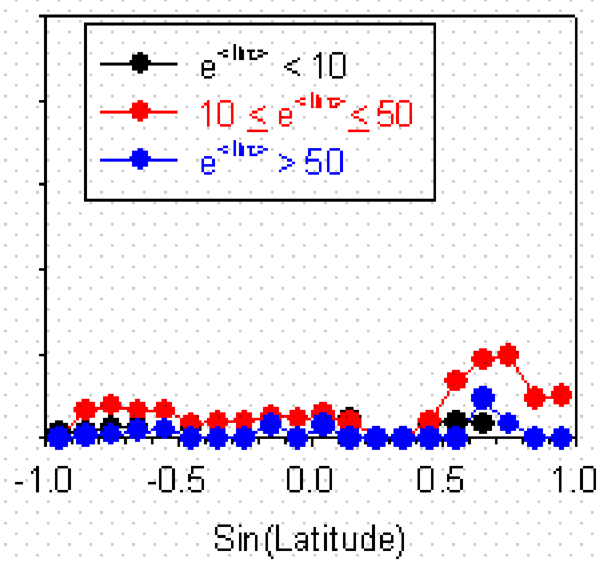
Frequency of 1° Regions: Nov 2000-April 2001



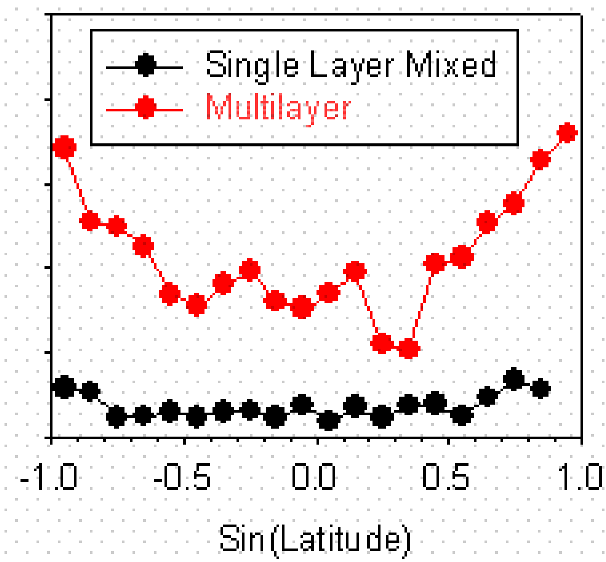
Single Layer Water Clouds



Single Layer Ice Clouds

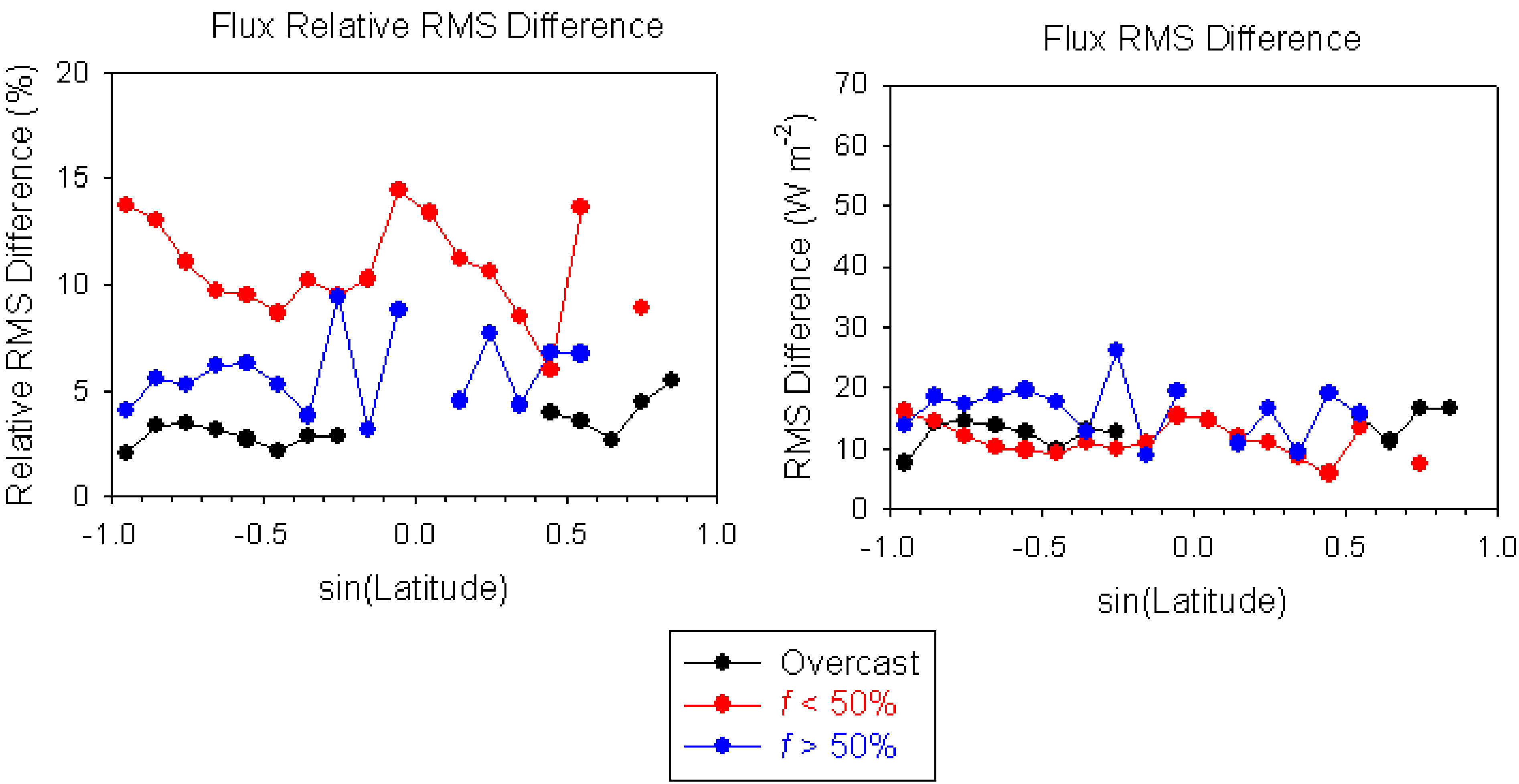


Single Layer Mixed+Multilayer



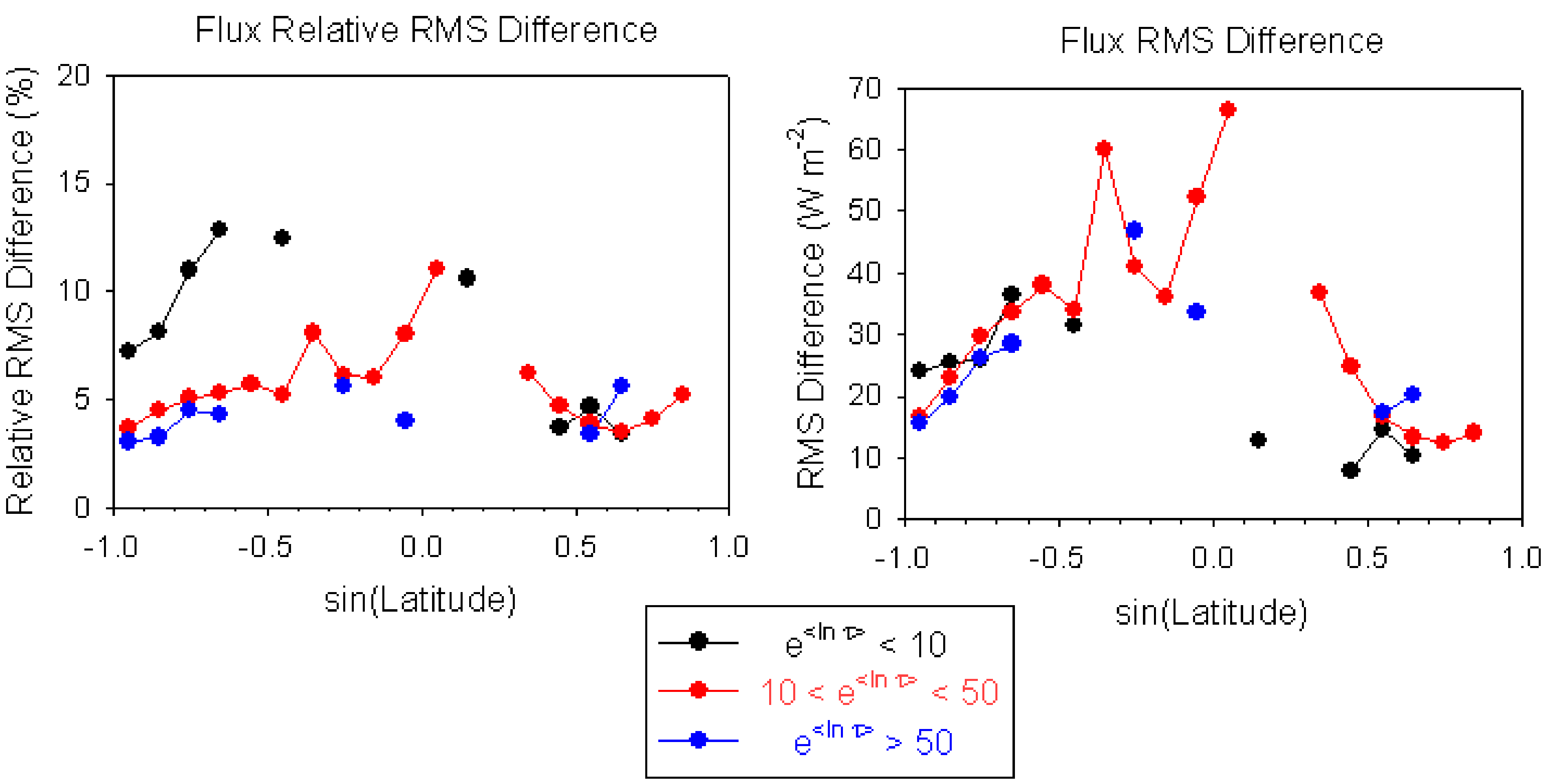
Instantaneous SW TOA Flux Consistency Tests: 1° Regions
(F(Nadir) vs F(60° < θ ≤ 70°); November to April, 2000, 2001)

Single Layer Water Clouds Over Ocean



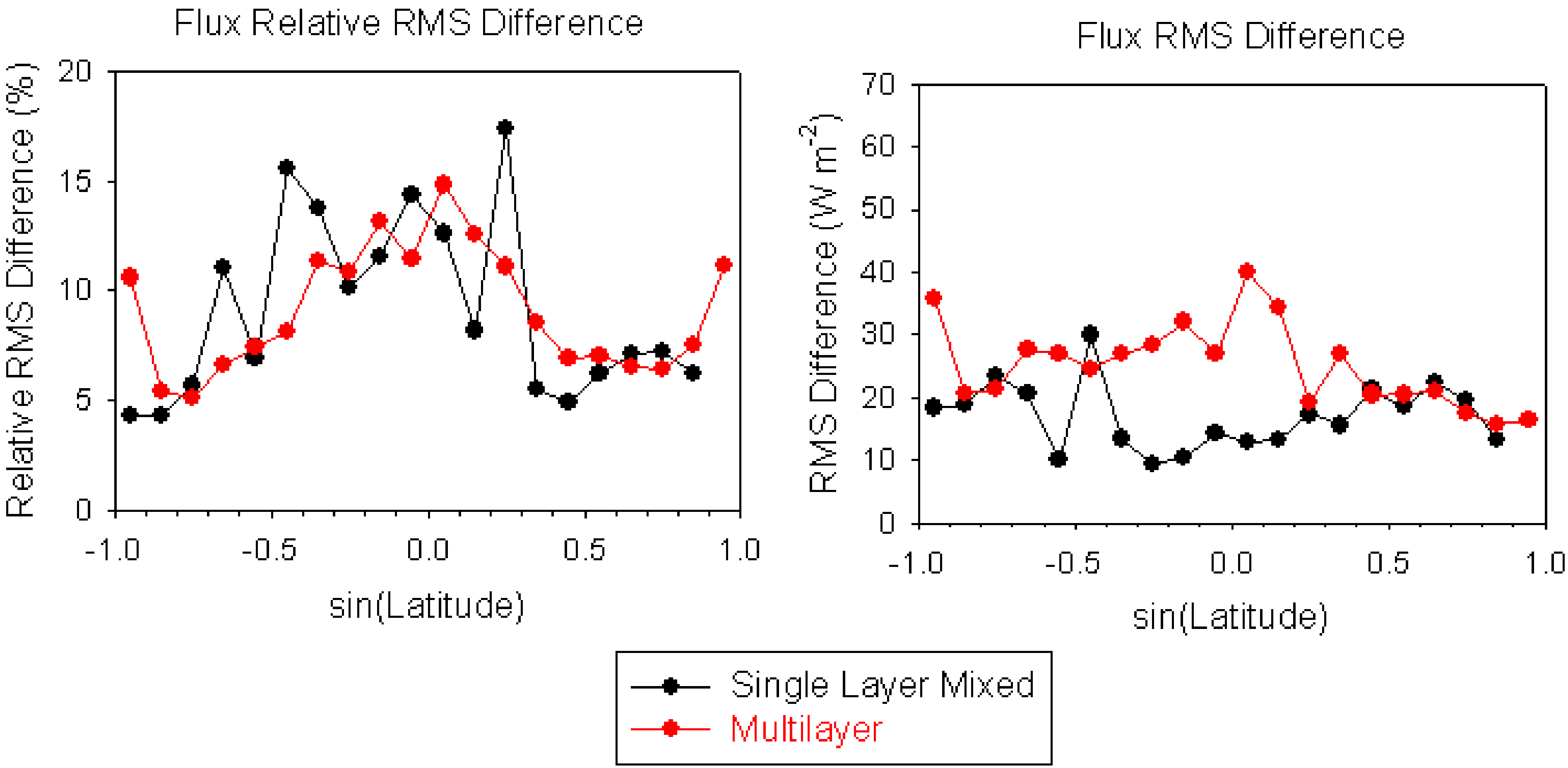
Instantaneous SW TOA Flux Consistency Tests: 1° Regions
(F(Nadir) vs F(60° < θ ≤ 70°); November to April, 2000, 2001)

Single Layer Ice Clouds Over Ocean



Instantaneous SW TOA Flux Consistency Tests: 1° Regions
(F(Nadir) vs F(60° < θ ≤ 70°); November to April, 2000, 2001)

Single Layer Mixed and Multilayer Clouds Over Ocean



Terra SW ADMs – Clear Land & Desert

Terra SW ADMs – 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.

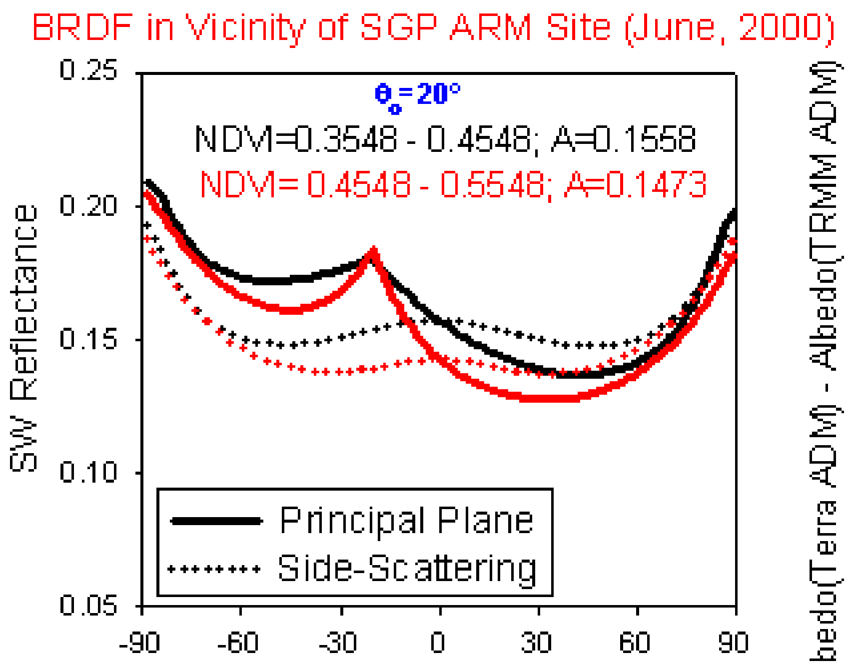
$$r(\mu,\phi,\mu_o) = \frac{1}{4}\frac{\omega}{\mu+\mu_o}\left\{1-\exp\left[-\tau\left(\frac{1}{\mu}+\frac{1}{\mu_o}\right)\right]\right\}\cdot\left\{P(\alpha)\left[1+B(\alpha')\right]\right\}+\frac{1}{4}\frac{\omega}{\mu+\mu_o}$$

$$\cdot\left[H^{(0)}(\mu)H^{(0)}(\mu_o)(1-e(\mu+\mu_o)-b(1-\omega)\mu\mu_o+b(1-\mu^2)^{1/2}\cdot(1-\mu_o^2)^{1/2}H^{(1)}(\mu)H^{(1)}(\mu_o)\cos\phi\right]$$

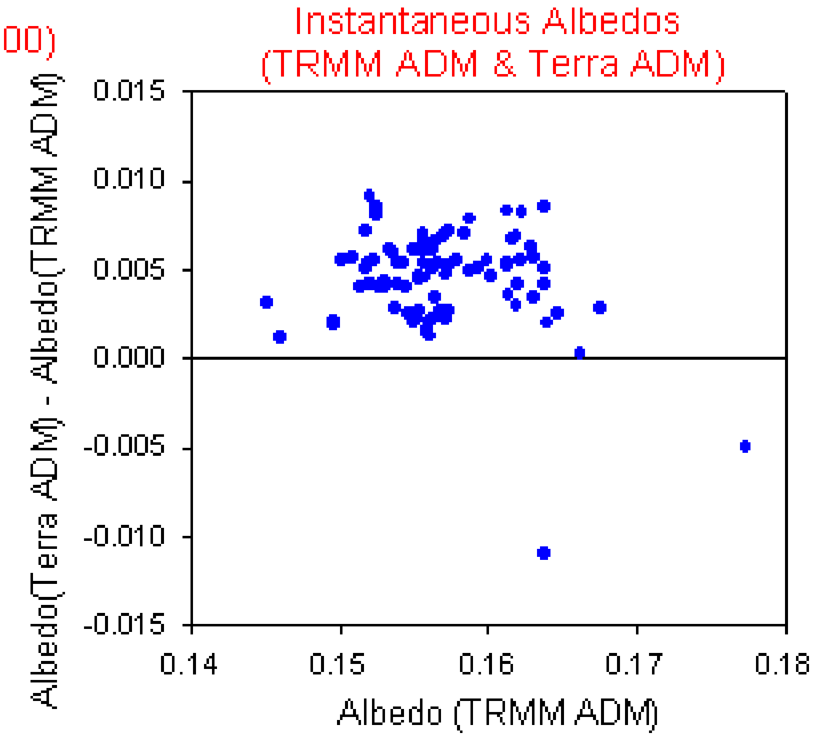
$$-\frac{1}{4}\frac{\omega}{\mu+\mu_o}P'(\alpha)+\left(d_o+\frac{d_1}{\mu+\mu_o}\right)$$

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

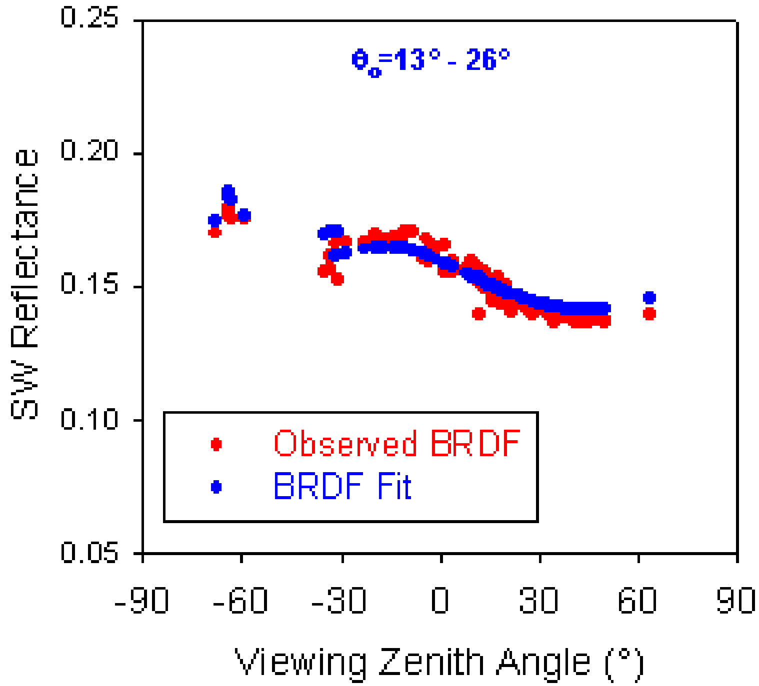
-"Hot-spot" modeled using empirical term (Hapke, 1986).



BRDF in Vicinity of SGP ARM Site (June, 2000)
θo=20°
NDM=0.3548 - 0.4548; A=0.1558
NDM= 0.4548 - 0.5548; A=0.1473
SW Reflectance
0.25
0.20
0.15
0.10
0.05
-90
-60
-30
0
30
60
90
Principal Plane
Side-Scattering

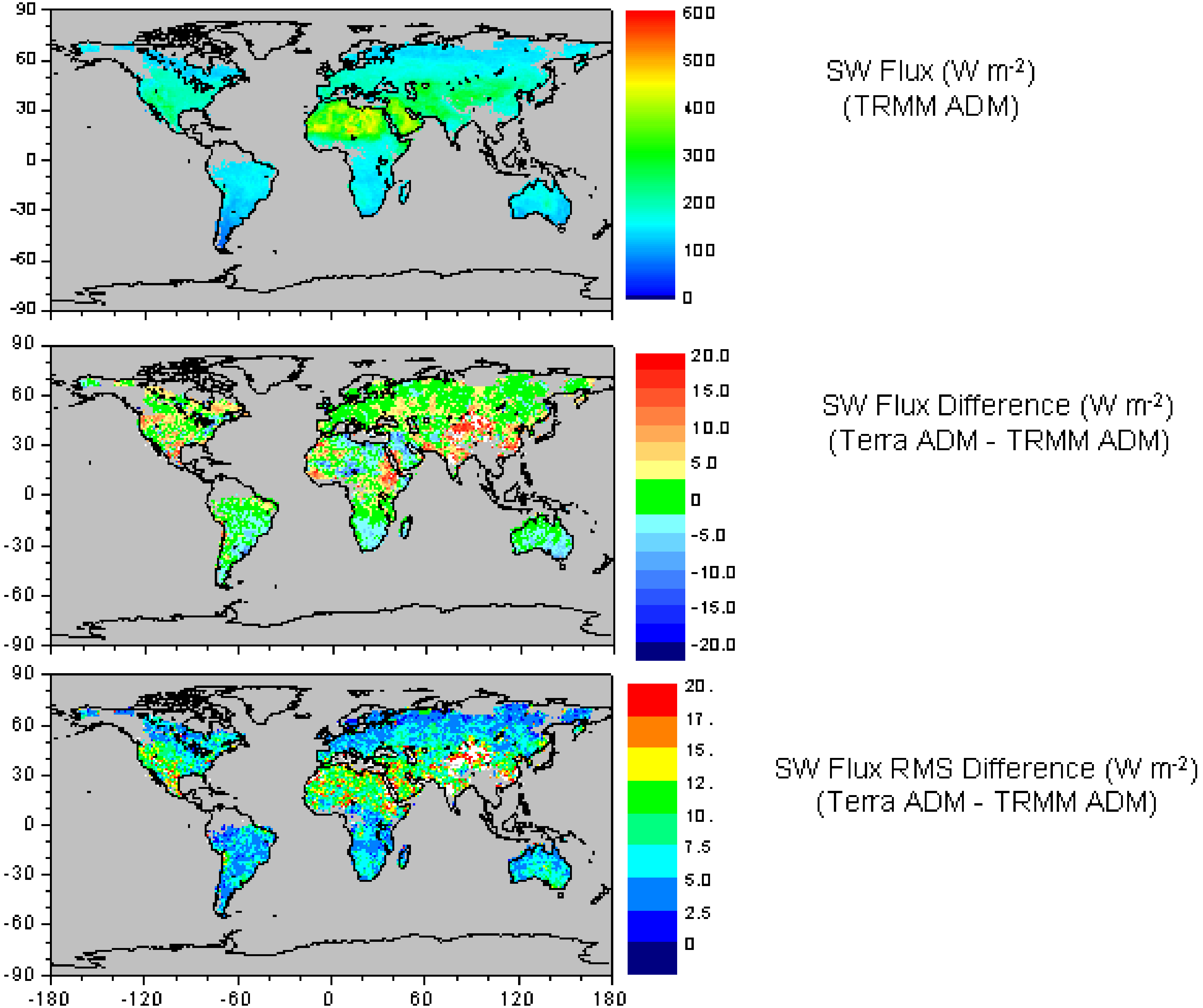


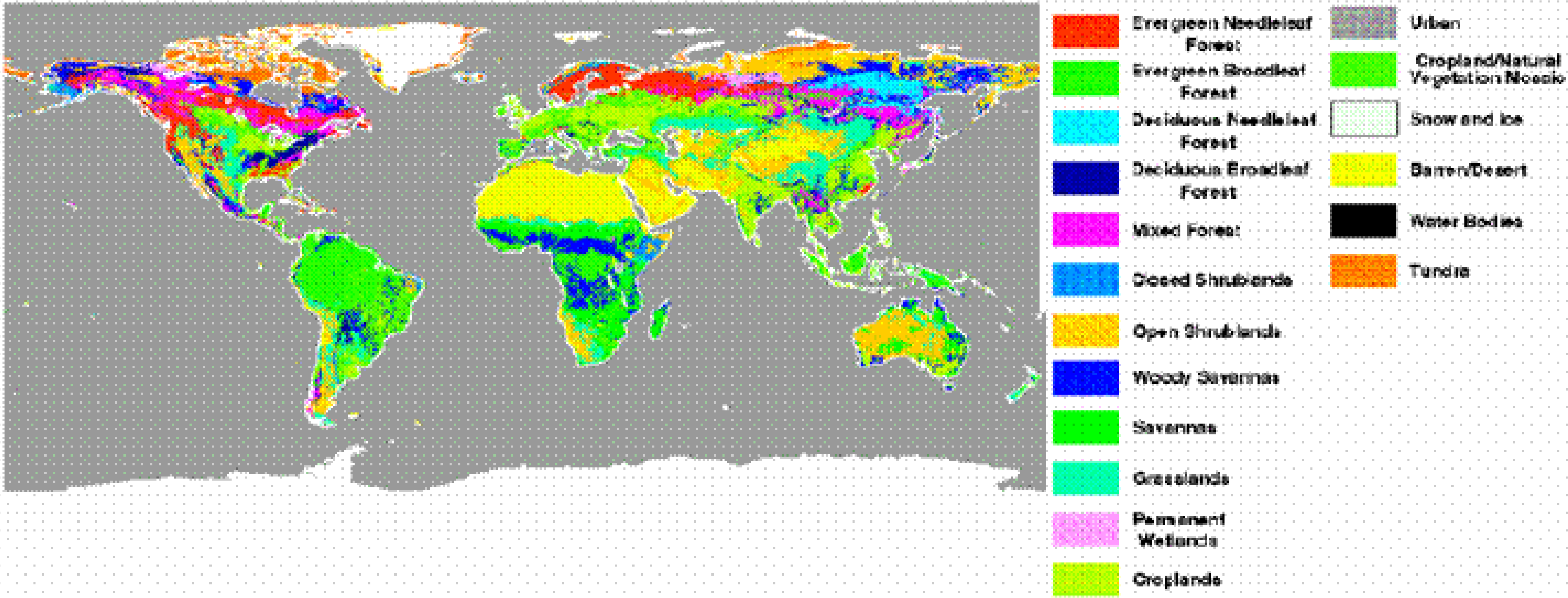
Instantaneous Albedos
(TRMM ADM & Terra ADM)
Albedo(Terra ADM) - Albedo(TRMM ADM)
0.015
0.010
0.005
0.000
-0.005
-0.010
-0.015
0.14
0.15
0.16
0.17
0.18
Albedo (TRMM ADM)



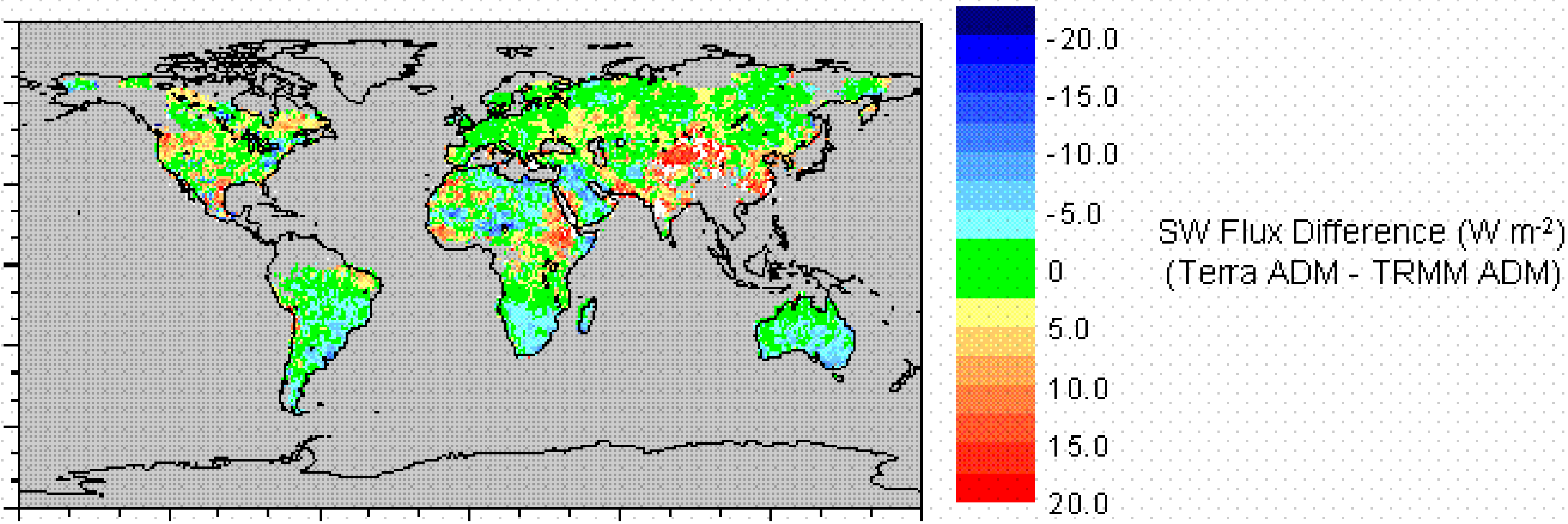
θo=13° - 26°
SW Reflectance
0.25
0.20
0.15
0.10
0.05
-90
-60
-30
0
30
60
90
Viewing Zenith Angle (°)
Observed BRDF
BRDF Fit

Clear Land SW TOA Flux: Terra, June 2000 (RAP+FAP)

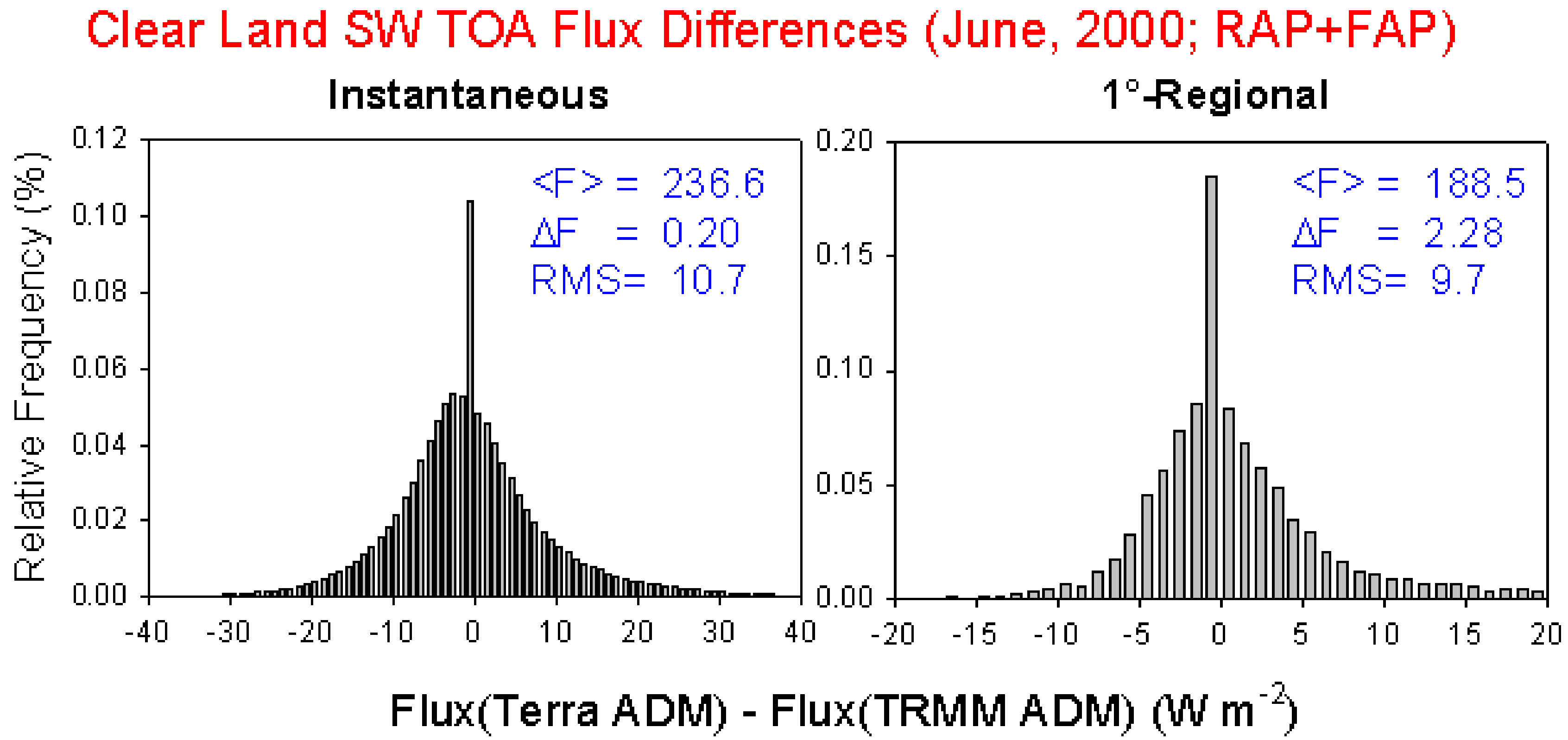




Evergreen Needleleaf Forest
Evergreen Broadleaf Forest
Deciduous Needleleaf Forest
Deciduous Broadleaf Forest
Mixed Forest
Closed Shrublands
Open Shrublands
Woody Savannas
Savannas
Grasslands
Permanent Wetlands
Croplands
Urban
Cropland/Natural Vegetation Mosaic
Snow and Ice
Barren/Desert
Water Bodies
Tundra



-20.0
-15.0
-10.0
-5.0
0
5.0
10.0
15.0
20.0
SW Flux Difference (W m-2)
(Terra ADM - TRMM ADM)


Clear Land SW TOA Flux Differences (June, 2000; RAP+FAP)
Instantaneous
1°-Regional
Relative Frequency (%)
<F> = 236.6
ΔF = 0.20
RMS= 10.7
<F> = 188.5
ΔF = 2.28
RMS= 9.7
Flux(Terra ADM) - Flux(TRMM ADM) (W m-2)

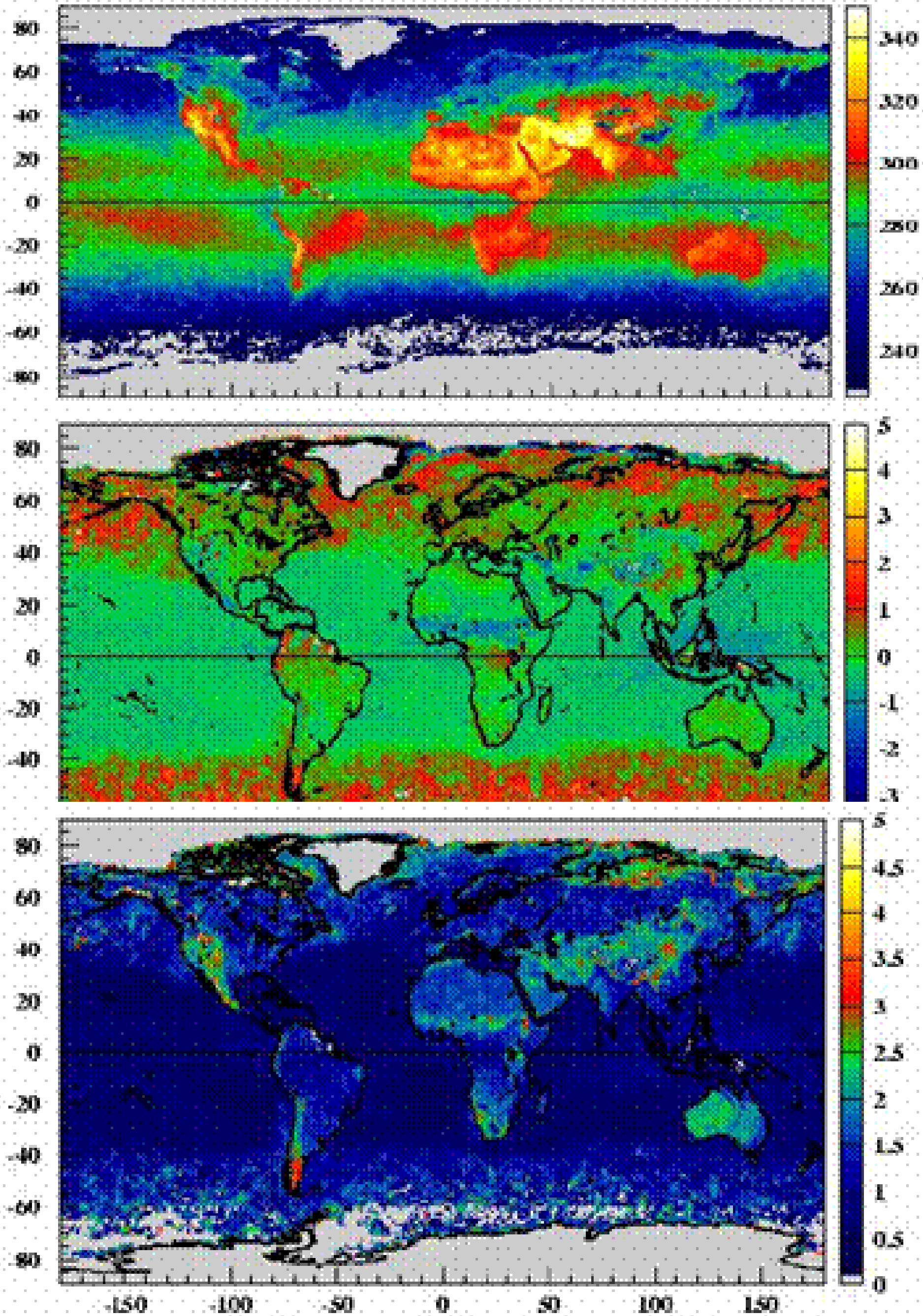
Terra LW ADMs – Clear Ocean, Land & Desert

See Manalo-Smith ADM WG Presentation

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) $\leq$33 33 – 66 $\geq$ 66	Intervals (cm) $\leq$1 1 - 3 3 - 5 > 5
Vertical Temperature Change	Intervals (Percentiles) Inversion ($\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

Clear-Sky LW TOA Flux: Terra, 422 Days (RAP+FAP)



LW Flux (W m^{-2})
(TRMM ADM)

Mean = 298.62 W m^{-2}

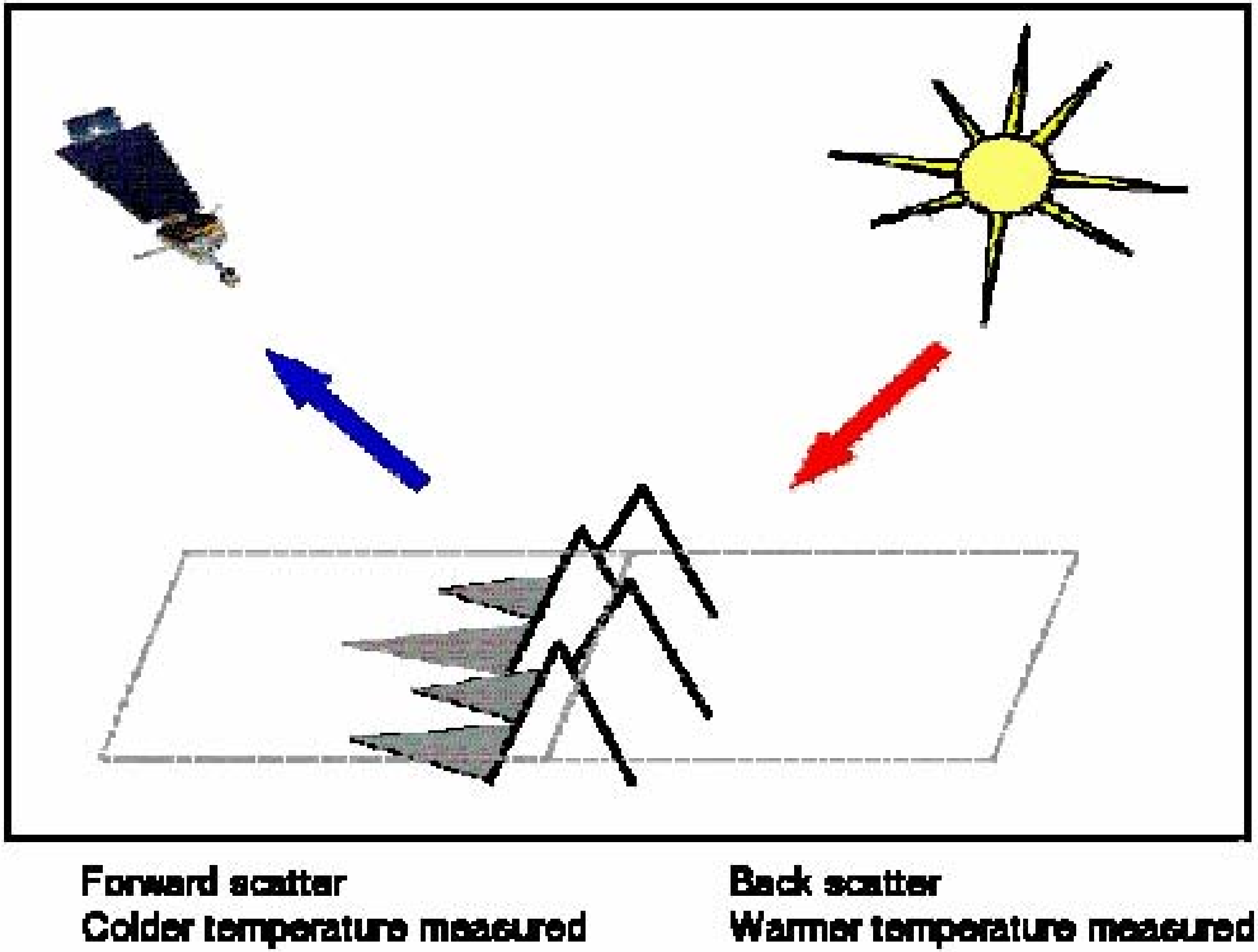
LW Flux Difference (W m^{-2})
(Terra ADM - TRMM ADM)

Mean Difference = -0.118 W m^{-2}

LW Flux RMS Difference (W m^{-2})
(Terra ADM - TRMM ADM)

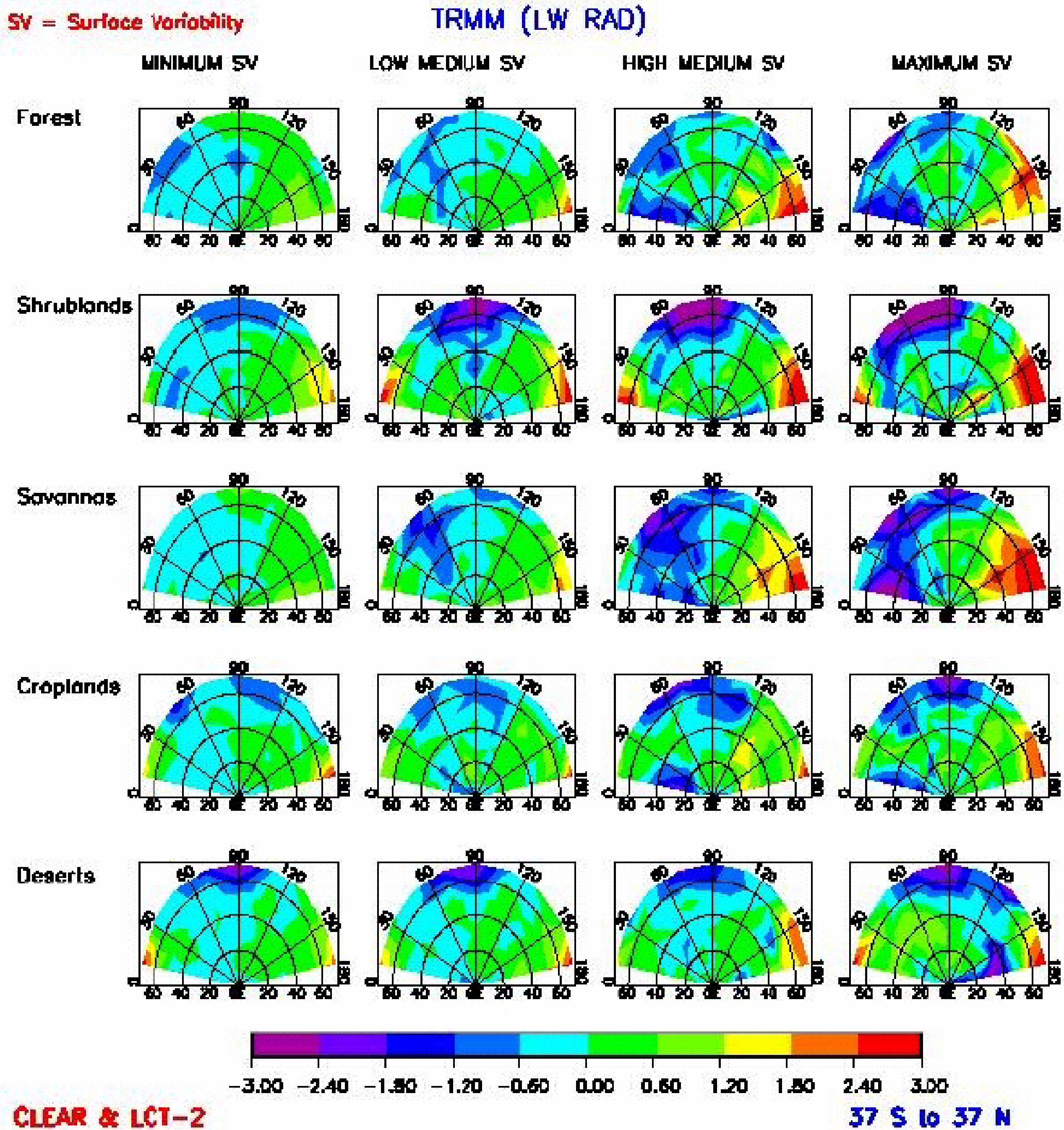
RMS = 1.507 W m^{-2}

Azimuthally-Dependent LW ADMs – Clear Land



Notice that the unlit side can be cooler because of shadowing.

See Arvind Gambheer ADM WG Presentation


SV = Surface Variability
TRMM (LW RAD)
MINIMUM SV
LOW MEDIUM SV
HIGH MEDIUM SV
MAXIMUM SV
Forest
Shrublands
Savannas
Croplands
Deserts
−3.00
−2.40
−1.80
−1.20
−0.60
0.00
0.60
1.20
1.80
2.40
3.00
CLEAR & LCT-2
37 S to 37 N

Terra LW ADMs – Clouds Over Ocean

Terra LW ADMs – Clouds Over Ocean

-For Intervals of:

i) precipitable water (4 intervals)

ii) skin temperature (5 intervals)

iii) surface-cloud temp difference (5 intervals)

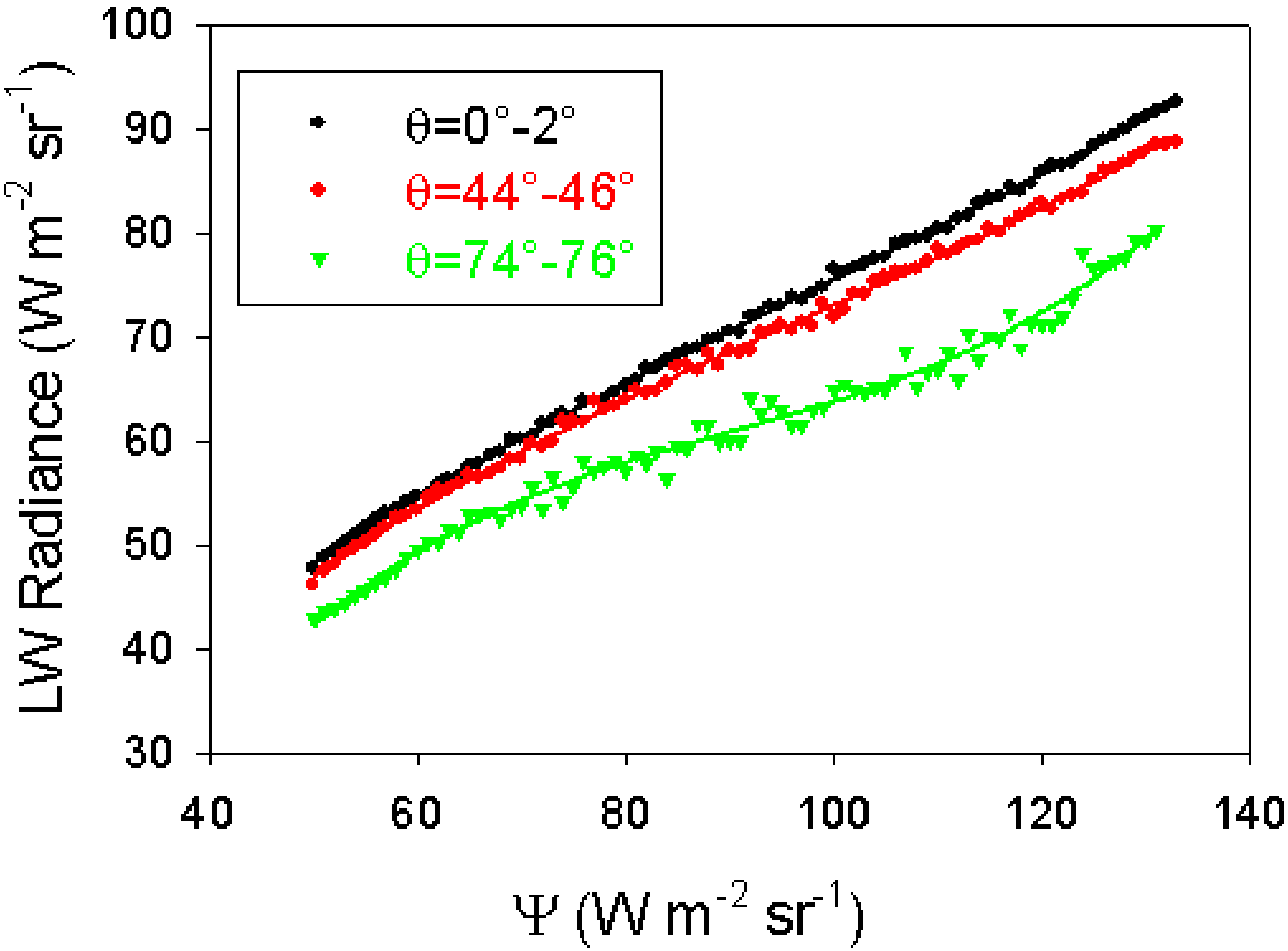
Derive functional fits between in 2° viewing zenith angle bins between CERES LW radiances and the parameter ψ defined by:

$$\psi(\Delta w, \Delta z_t; f, \varepsilon_s, T_s, \varepsilon_c, T_c) = (1 - f)\varepsilon_s B(T_s) + \sum_{j=1}^{2}\left(\varepsilon_s B(T_s)[1 - \varepsilon_{c_j}(\theta)] + \varepsilon_{c_j}(\theta) B(T_{c_j})\right) f_j$$

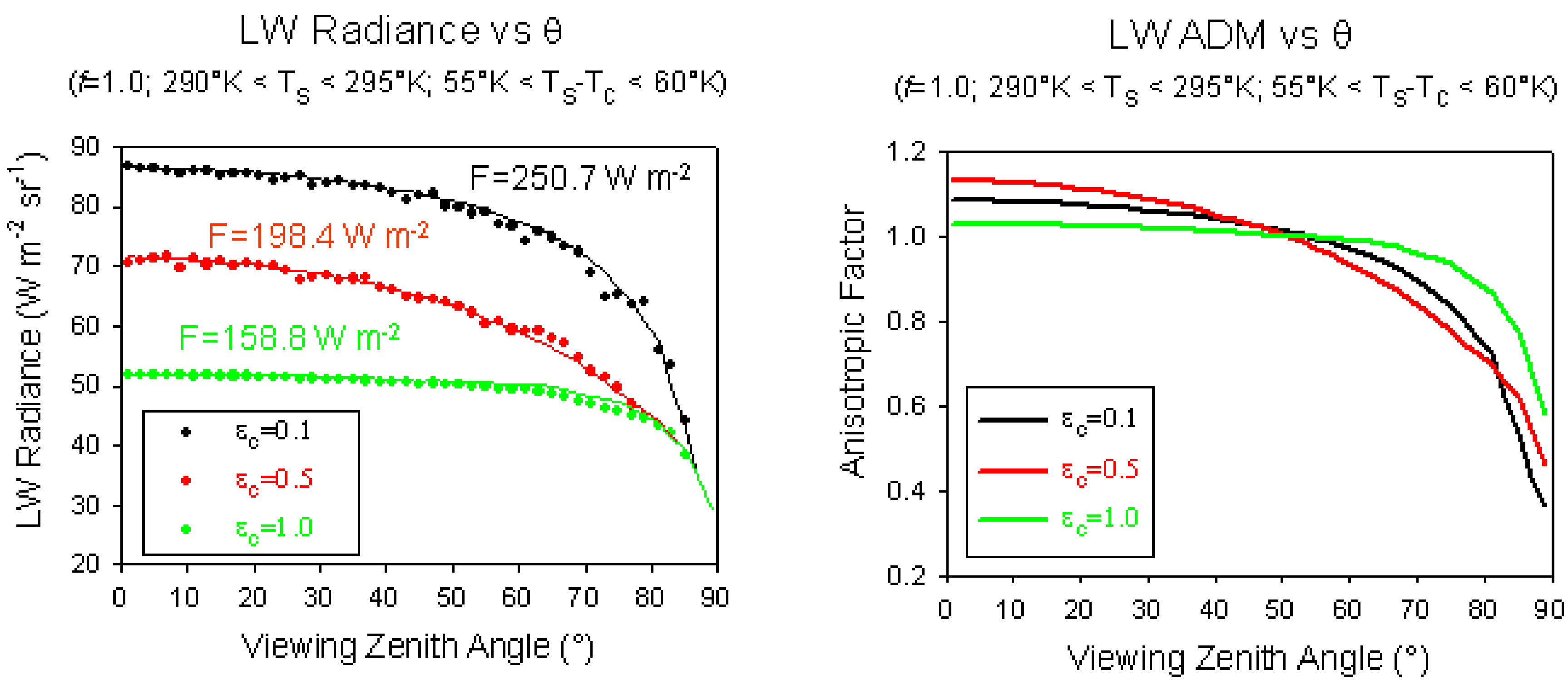
$$\varepsilon_c(\theta) = 1 - e^{\tau_a/\cos\theta}; \quad f = f_1 + f_2$$

LW Radiance vs Ψ

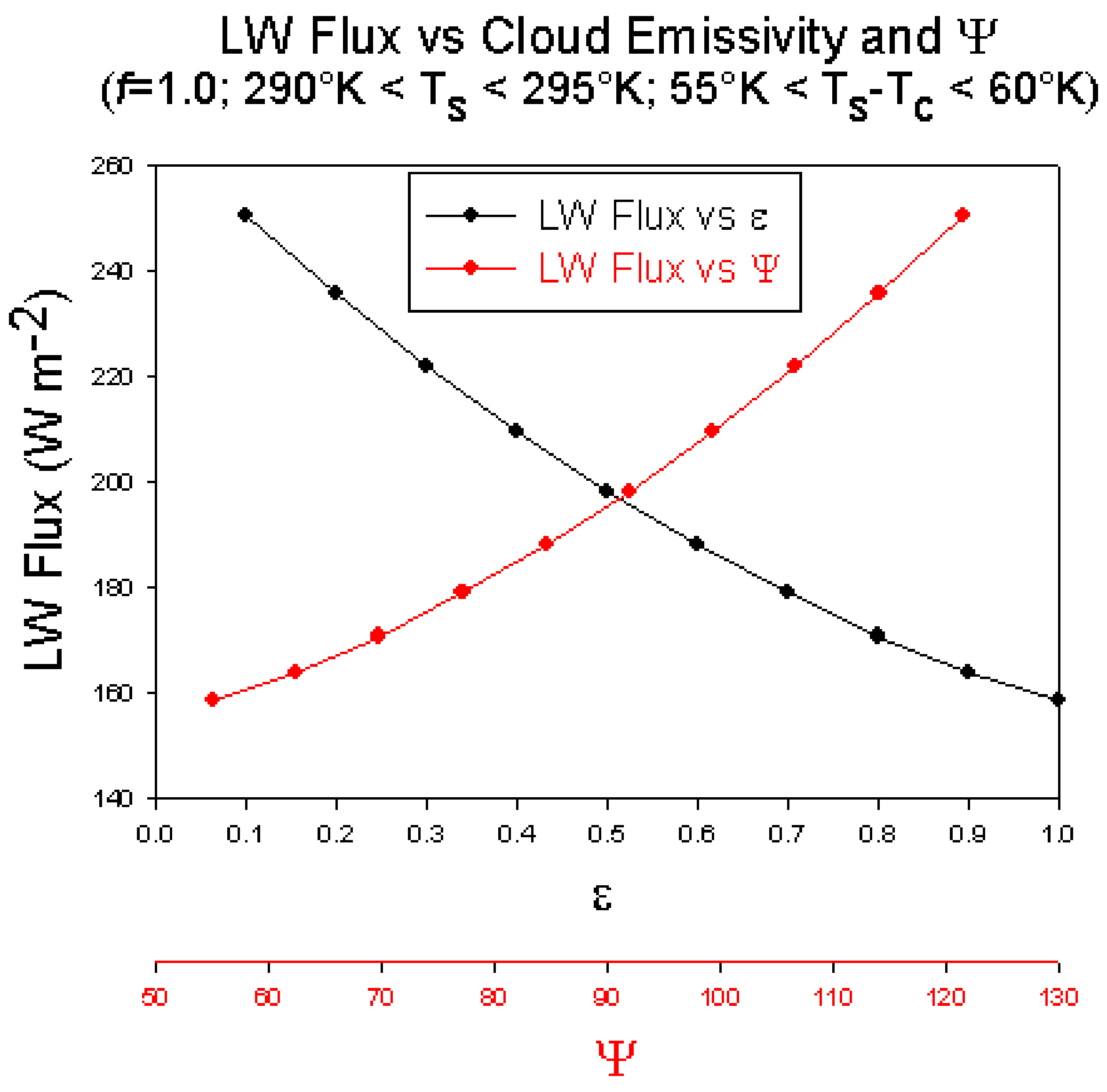
(290°K < T_s < 295°K; 55°K < T_s-T_c < 60°K)



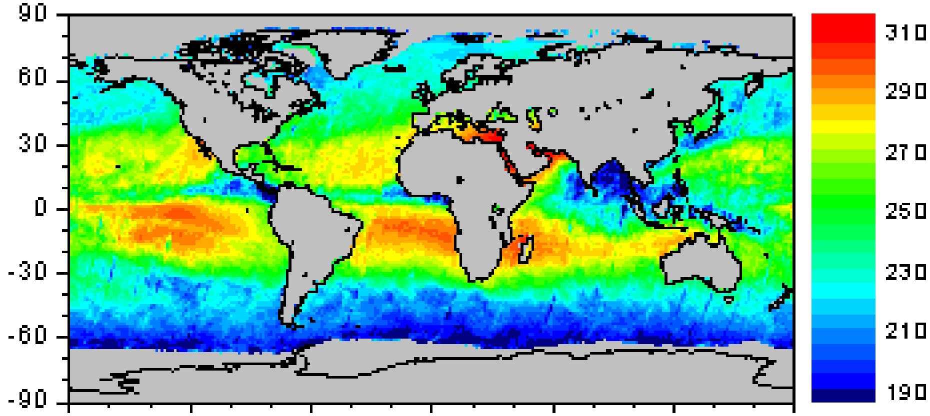
$$\psi(\Delta w, \Delta z_t; f, \varepsilon_s, T_s, \varepsilon_c, T_c) = (1-f)\varepsilon_s B(T_s) + \sum_{j=1}^{2}\left(\varepsilon_s B(T_s)(1-\varepsilon_{c_j}) + \varepsilon_{c_j} B(T_{c_j})\right) f_j$$



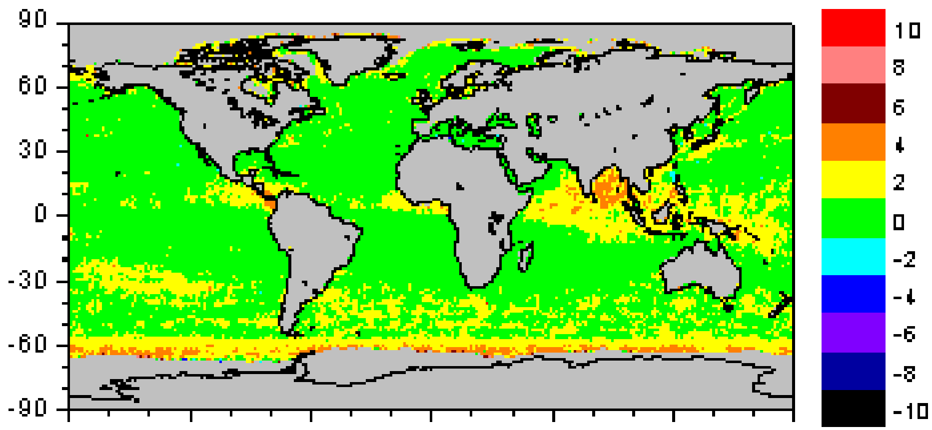
LW Radiance vs θ
(f=1.0; 290°K < T_S < 295°K; 55°K < T_S-T_C < 60°K)
F=250.7 W m-2
F=198.4 W m-2
F=158.8 W m-2
LW Radiance (W m-2 sr-1)
Viewing Zenith Angle (°)
ε_c=0.1
ε_c=0.5
ε_c=1.0
90
80
70
60
50
40
30
20
0
10
20
30
40
50
60
70
80
90
LW ADM vs θ
(f=1.0; 290°K < T_S < 295°K; 55°K < T_S-T_C < 60°K)
Anisotropic Factor
Viewing Zenith Angle (°)
ε_c=0.1
ε_c=0.5
ε_c=1.0
1.2
1.0
0.8
0.6
0.4
0.2
0
10
20
30
40
50
60
70
80
90


LW Flux vs Cloud Emissivity and Ψ
(f=1.0; 290°K < T_s < 295°K; 55°K < T_s-T_c < 60°K)
LW Flux (W m^-2)
260
240
220
200
180
160
140
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0
ε
50
60
70
80
90
100
110
120
130
Ψ
LW Flux vs ε
LW Flux vs Ψ

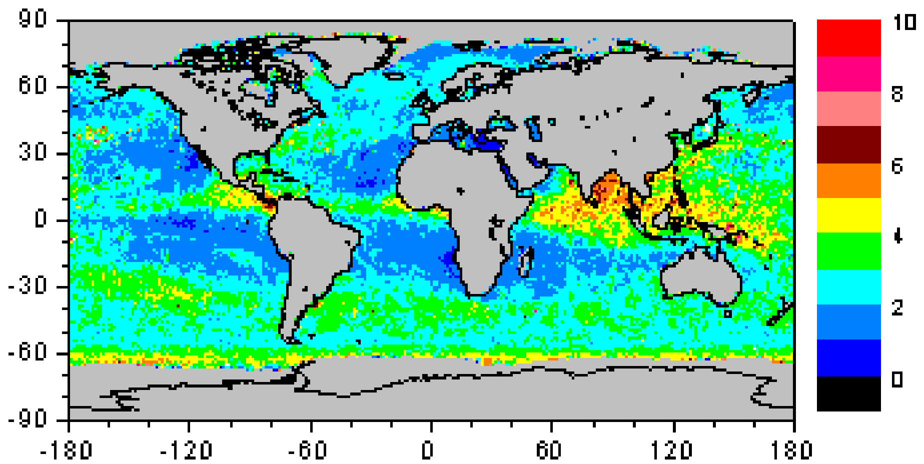
All-Sky Ocean LW TOA Flux: Terra, June 2000 (RAP+FAP)



LW Flux ($W\ m^{-2}$)
(TRMM ADM)

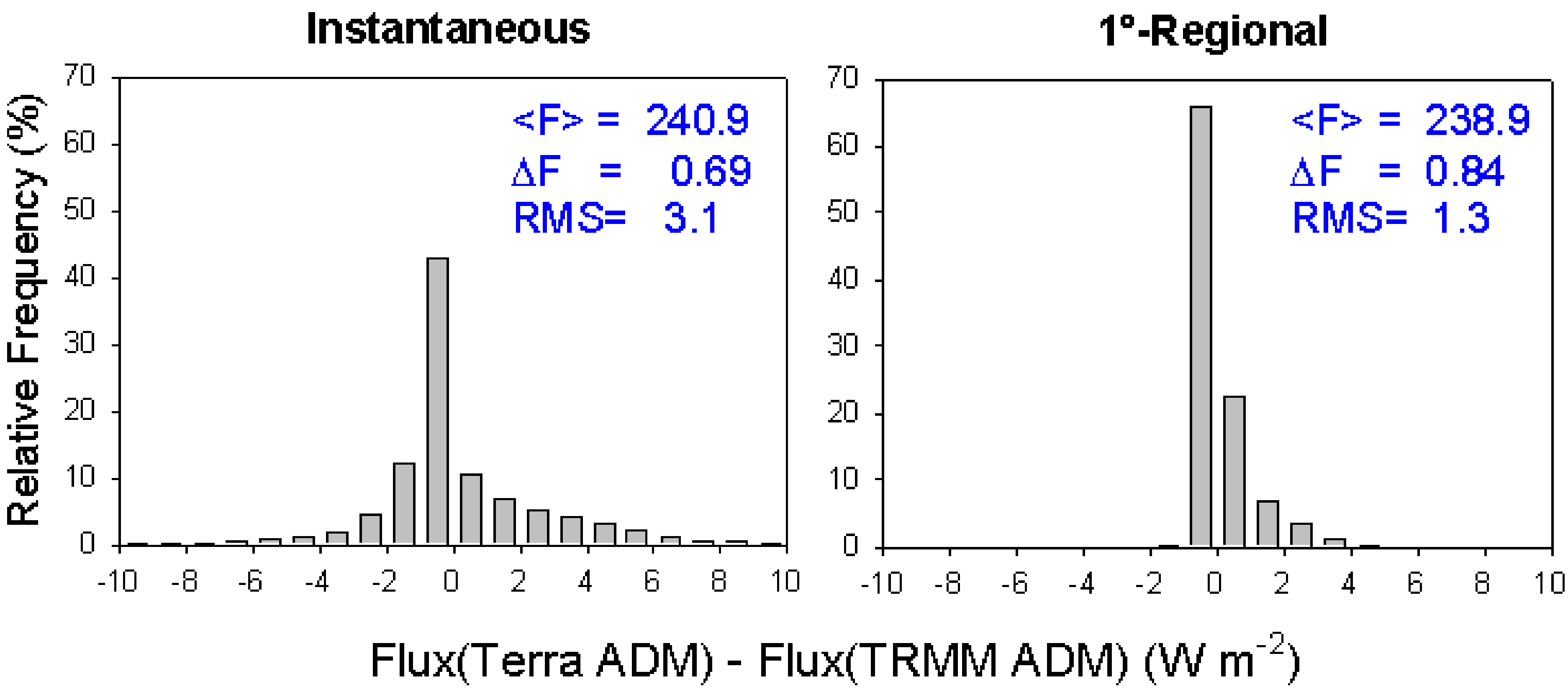


LW Flux Difference ($W\ m^{-2}$)
(Terra ADM - TRMM ADM)



LW Flux RMS Difference ($W\ m^{-2}$)
(Terra ADM - TRMM ADM)

All-Sky Ocean LW TOA Flux Differences (June, 2000; RAP+FAP)



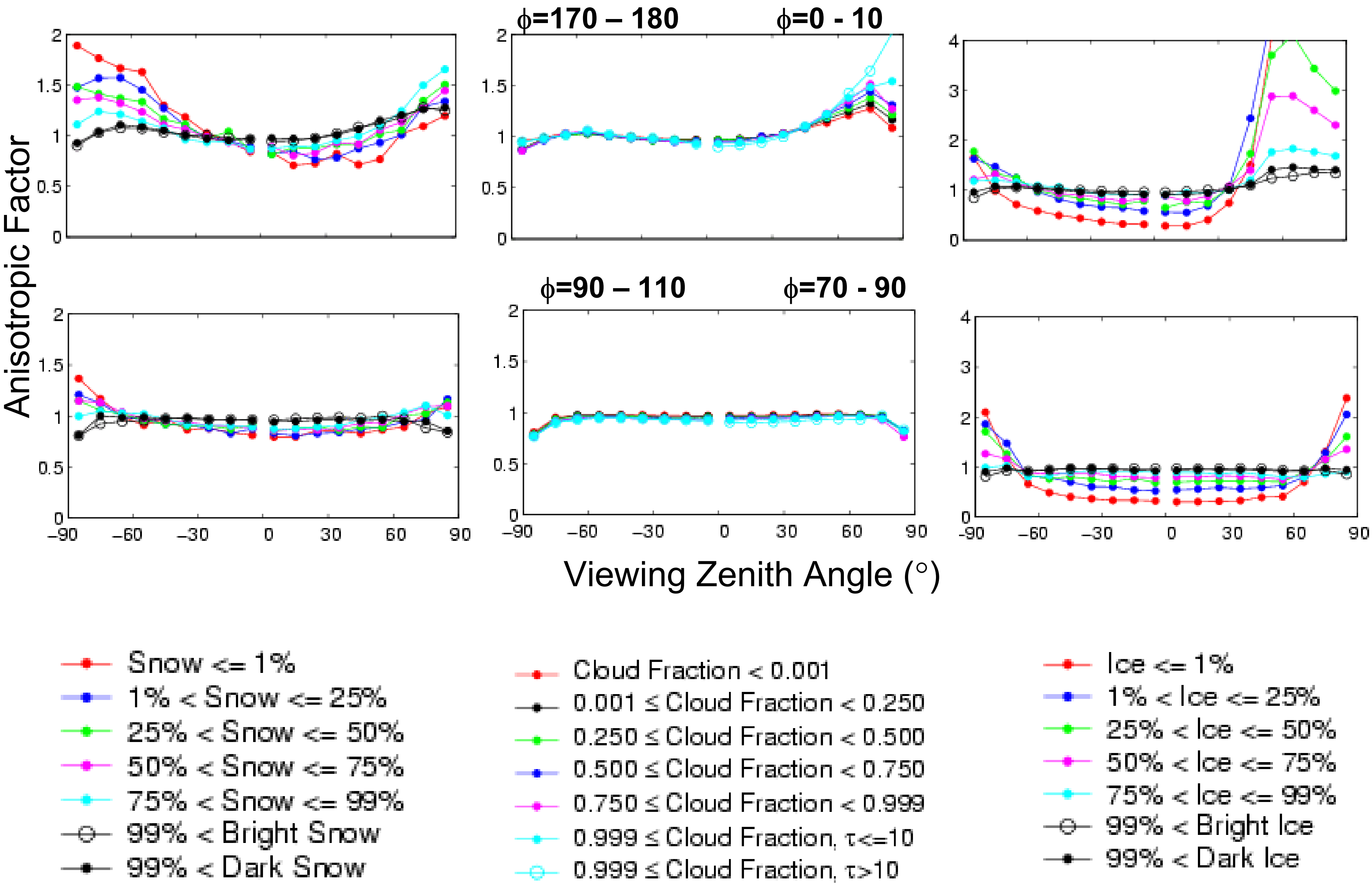
Snow, Sea Ice & Fresh Snow

Terra SW & LW ADMs – Snow, Sea-Ice

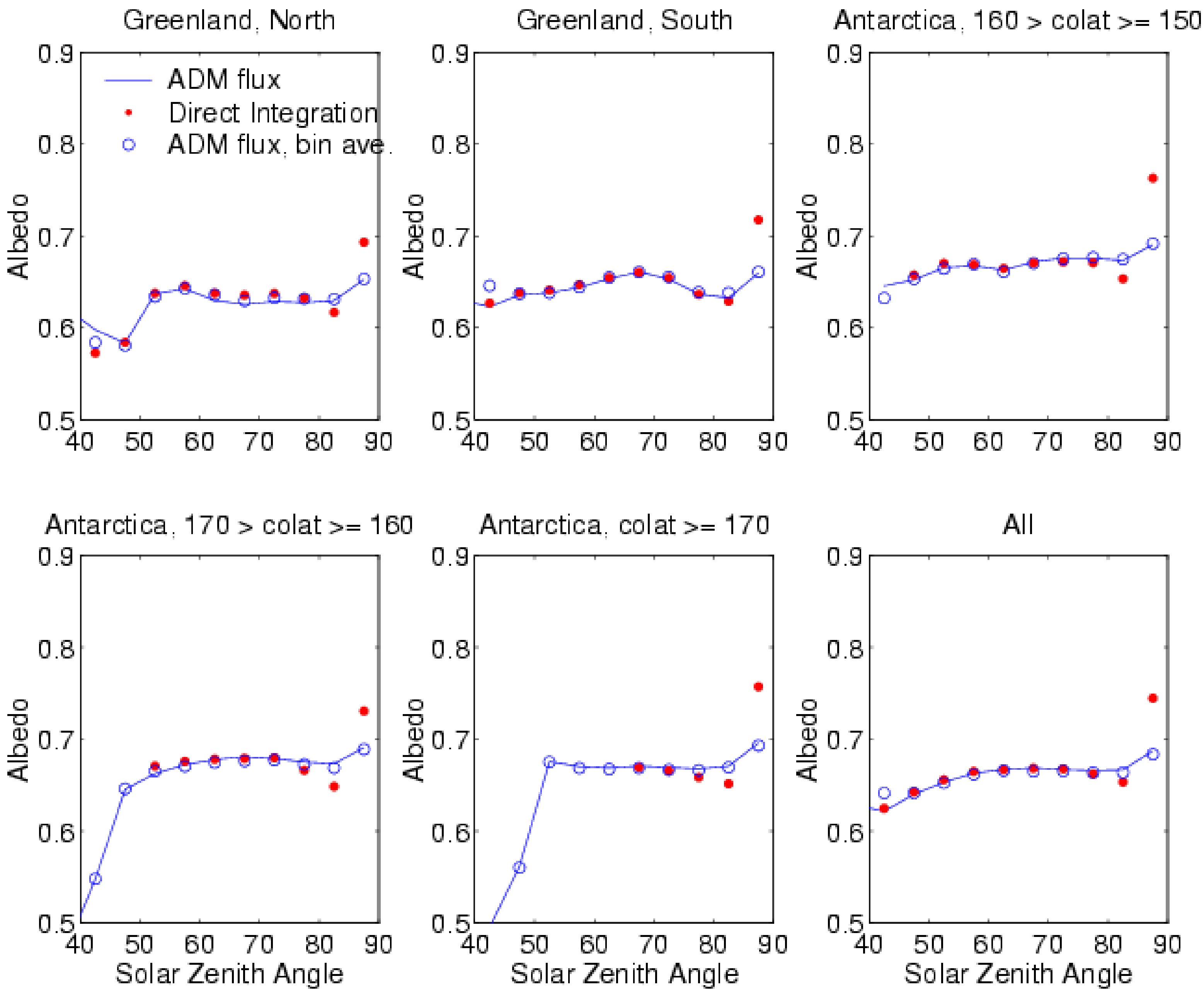
	Shortwave	Longwave
Permanent Snow SW (8) LW (132)	Cloud Fraction (6) Cloud (2)	Cloud Fraction (6) Tsfc (6) Tsfc-Tcld (5)
Fresh Snow SW(23) LW(132)	Cloud Fraction (6) Snow Fraction (6) Snow (2), Cloud (2)	Cloud Fraction (6) Tsfc (6) Tsfc-Tcld (5)
Sea Ice SW (23) LW (132)	Cloud Fraction (6) Ice Fraction (6) Ice (2), Cloud (2)	Cloud Fraction (6) Tsfc (6) Tsfc-Tcld (5)

See Seiji Kato ADM WG Presentation

Sample SW ADMs: θ_o=55° - 60°

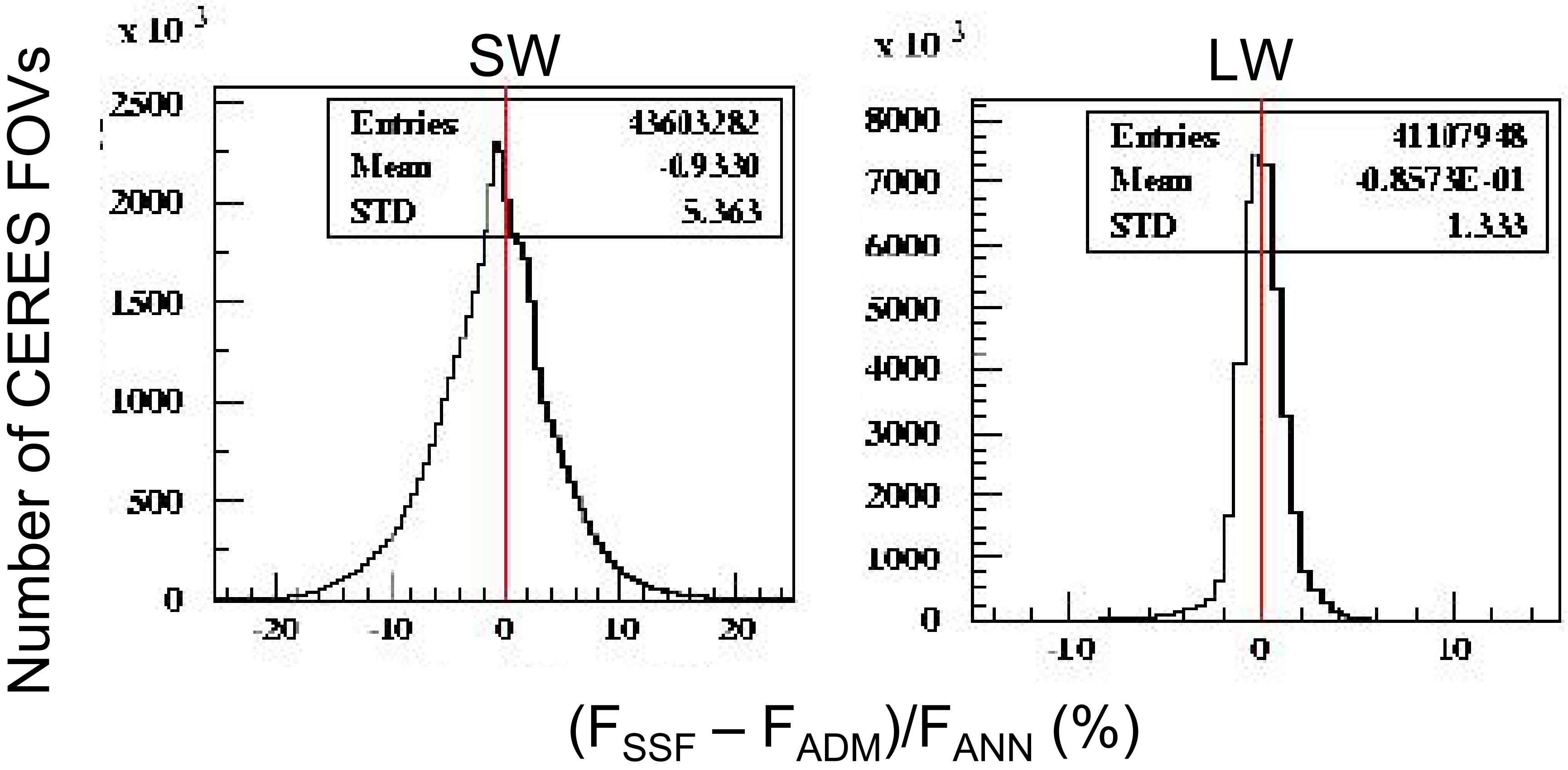


TOA Albedo Direct Integration Tests: Snow



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.



See Konstantin Loukachine ADM WG Presentation

Conclusions

- Early results from Terra ADMs look promising. Improvement over TRMM ADMs especially outside of Tropics.

- Final Terra ADMs expected to be completed in September, 2003.

- More work needed to evaluate quality of 1°-resolution SW clear land ADMs and fits for ocean LW ADMs.

- SW and LW ADMs yet to be developed for clouds over land and desert.