Validation of CERES/TRMM SSF Edition 2 Angular Distribution Models

Norman G. Loeb[1], Natividad Manalo-Smith[2],

Konstantin Loukachine[4], Seiji Kato[1], Yongxiang Hu[3]

[1]Hampton University, [2]AS&M, [3]NASA LaRC, [4]SAIC

Outline

- TOA Flux/ADM Production Schedule
- Recent Changes to SSF
- CERES ADM Types and Web Page
- SW Flux Validation
- LW and WN Flux Validation

TOA Flux Production Schedule

1. August 2001

- Delivery of SSF Edition 2 SW, LW & WN ADMs. ✓
- Prepare SSF Edition 2 validation results. ✓

2. September 2001

- Begin production of CERES/TRMM Edition 2 SSFs. ✓
- Complete SSF Edition 2 Quality Summary. ✗
- Archive SSF Edition 2 pending Science Team Approval. ✗

3. October 2001 – March 2002

- Preparation of 2-3 manuscripts for publication summarizing TRMM ADMs and validation results. ✗
- Begin developing CERES/Terra ADMs. ✗

Recent Changes to SSF (to appear in SSF Edition 2)

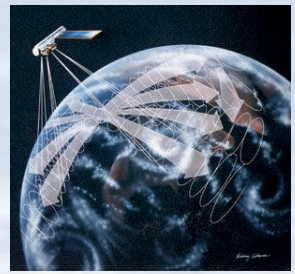
- Include all CERES footprints that have at least 1 VIRS pixel coverage (independent of whether imager data is bad).
  =>User's should carefully check SSF parameters: "percent imager coverage (SSF-54)" and "cloud property extrapolation over cloudy area (SSF-63)".

- Retain clear scenes over "hot" desert and land with saturated VIRS channel 4 radiances.
  - Use CERES WN brightness temperature threshold to identify clear scenes over very hot surfaces.

- Changed units of window (WN) unfiltered radiance and TOA flux from W m^{-2} μm^{-1} to W m^{-2}.
  - WN unfiltered radiance & flux is defined over 8.1 - 11.8 μm wavelength interval.

http://asd-www.larc.nasa.gov/Inversion/

CERES Inversion Group Home Page



Overview

Angular Distribution Models

ADM Version Summary

Validation Results

Publications

Conferences

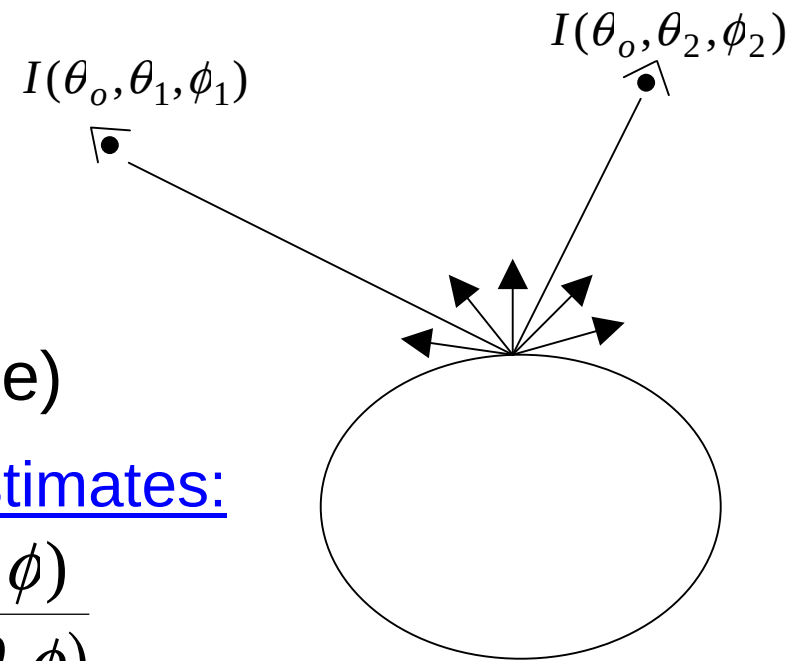
Inversion Production Code

Current Research

Relevant Links

Responsible NASA Official: Dr. Bruce A. Wielicki
Web Curator: Dr. K. Loukachine K.Loukachine@larc.nasa.gov

SW Flux & Albedo Estimation from ADMs



Reflectance (isotropic albedo):

$$r(\theta_o,\theta,\phi) = \frac{\pi I(\theta_o,\theta,\phi)}{\cos\theta_o \; S_o}$$

$(I(\theta_o,\theta,\phi) =$ measured radiance)

Instantaneous Flux & Albedo Estimates:

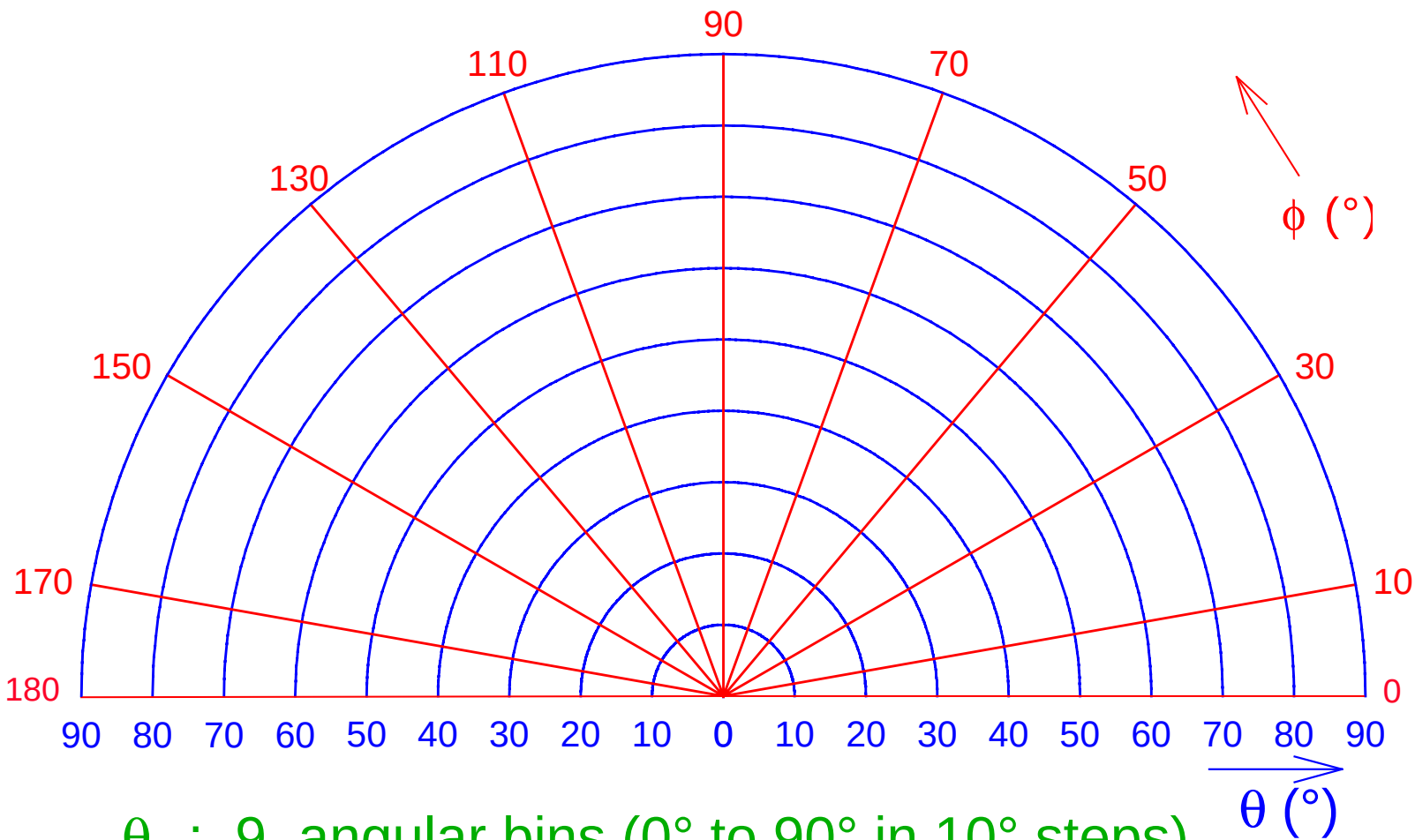
$$\hat{F} = \frac{\pi \, I(\theta_o,\theta,\phi)}{R_j(\theta_o,\theta,\phi)} \qquad \hat{A} = \frac{r(\theta_o,\theta,\phi)}{R_j(\theta_o,\theta,\phi)}$$

where,

$R_j(\theta_o,\theta,\phi)$ = SW Anisotropic Factor

$$R_j(\theta_o,\theta,\phi) = \frac{\bar{r}_j(\theta_o,\theta,\phi)}{\bar{A}_j(\theta_o)} = \frac{\bar{r}_j(\theta_o,\theta,\phi)}{\pi^{-1}\int_0^{2\pi}\int_0^{\frac{\pi}{2}} \bar{r}_j(\theta_o,\theta,\phi)\cos\theta d\theta d\phi}$$

CERES SW ADM Angular Bin Definitions



θ_o : 9 angular bins (0° to 90° in 10° steps)

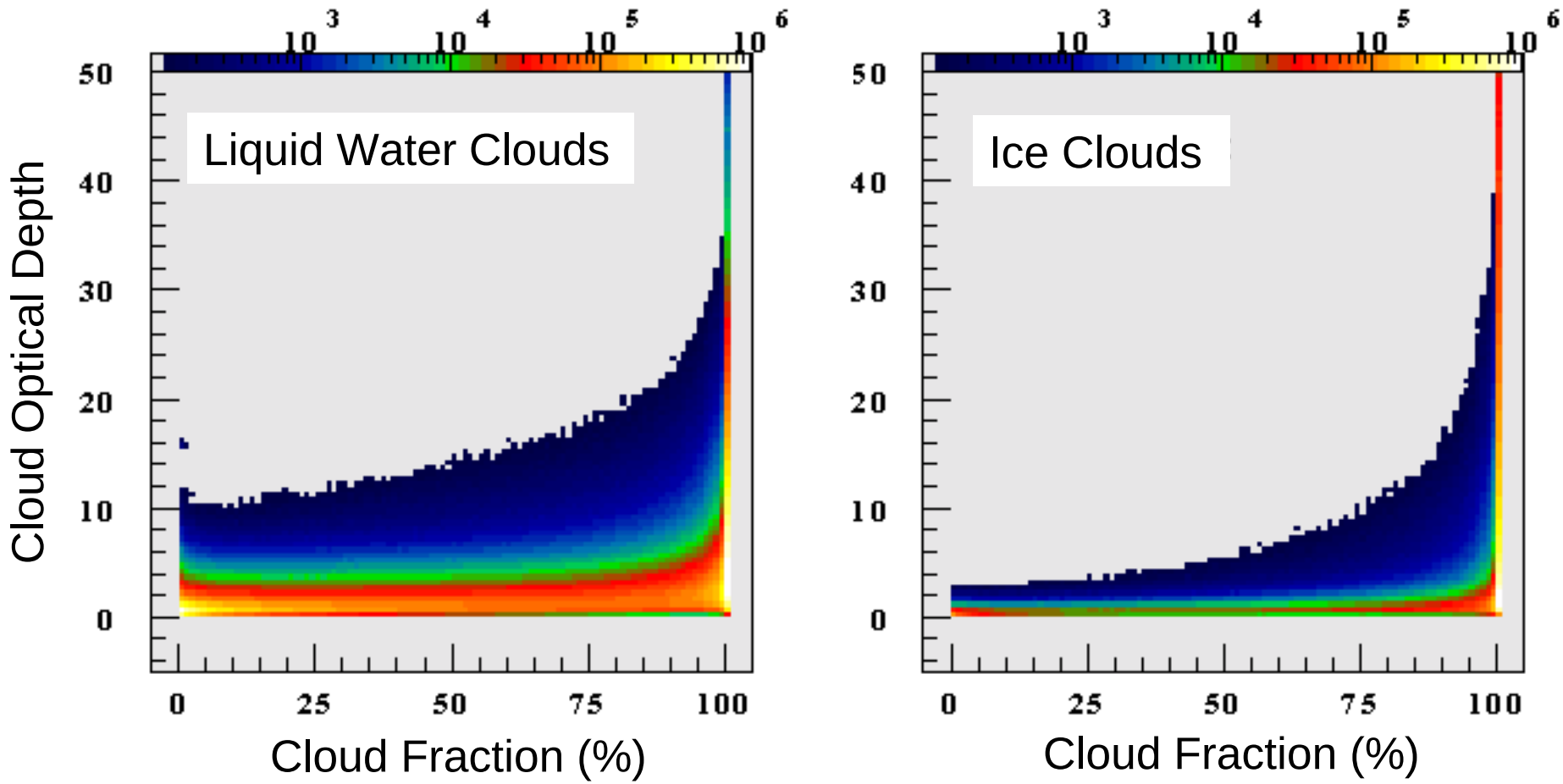
θ : 9 angular bins (0° to 90° in 10° steps)

ϕ : 10 angular bins (0° to 180° in 10° or 20° steps)

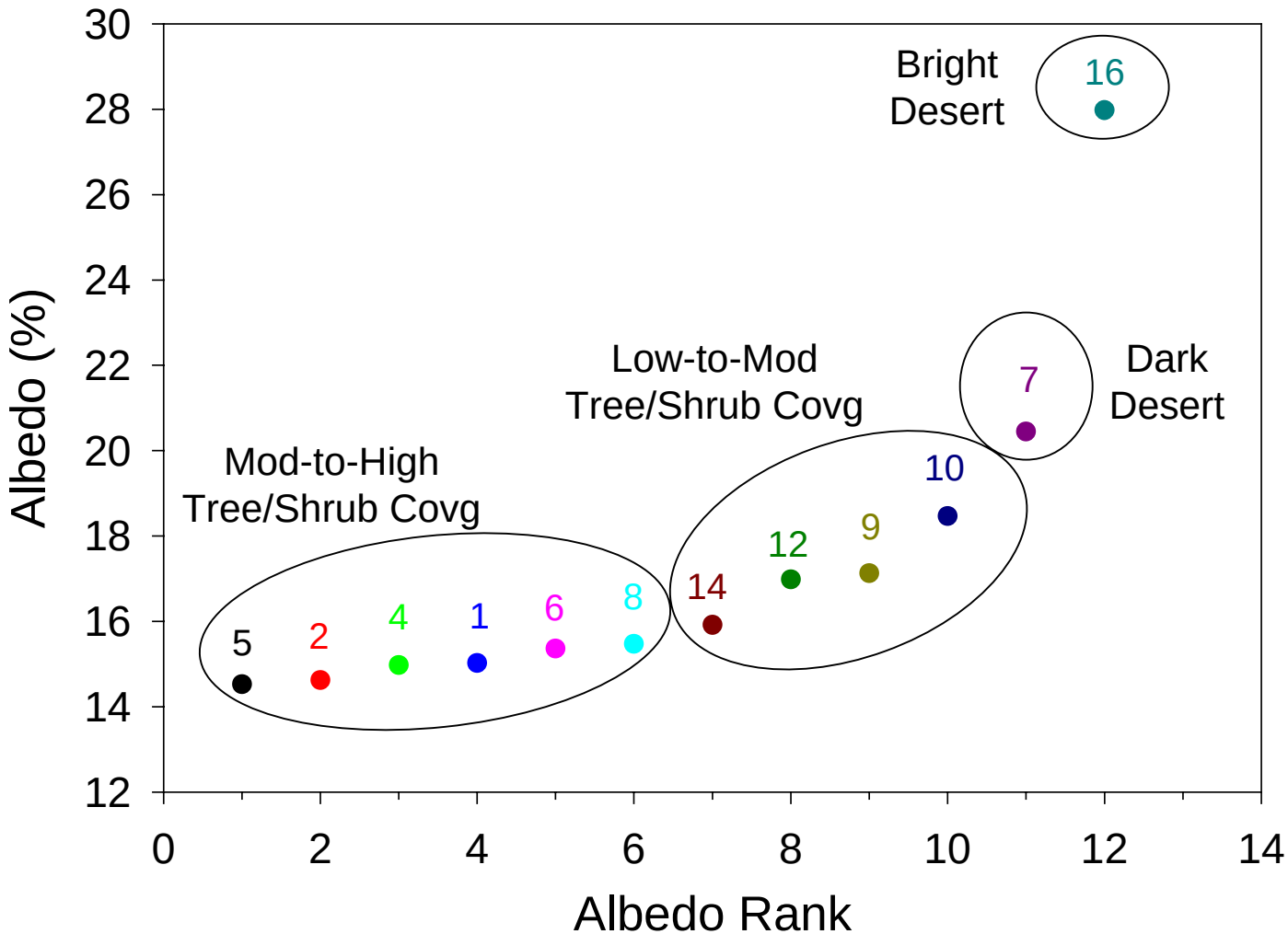
Scene Types for CERES/TRMM SW ADMs

ADM Category		Scene Type Stratification	Actual Total
Clear	Ocean	- 4 Wind Speed Intervals	4
	Land	- 2 IGBP Type Groupings	2
	Desert	- Bright and Dark	2
	Snow	- Theoretical	1
Cloud	Ocean	- Liquid and Ice - 12 Cloud Fraction Intervals - 14 Optical Depth Intervals	62 (L) 53 (I)
	Land	- 2 IGBP Type Groupings - Liquid and Ice - 5 Cloud Fraction Intervals - 6 Optical Depth Intervals	45
	Desert	- Bright and Dark Deserts - Liquid and Ice - 5 Cloud Fraction Intervals - 6 Optical Depth Intervals	33
	Snow	- Theoretical	1
Total			203

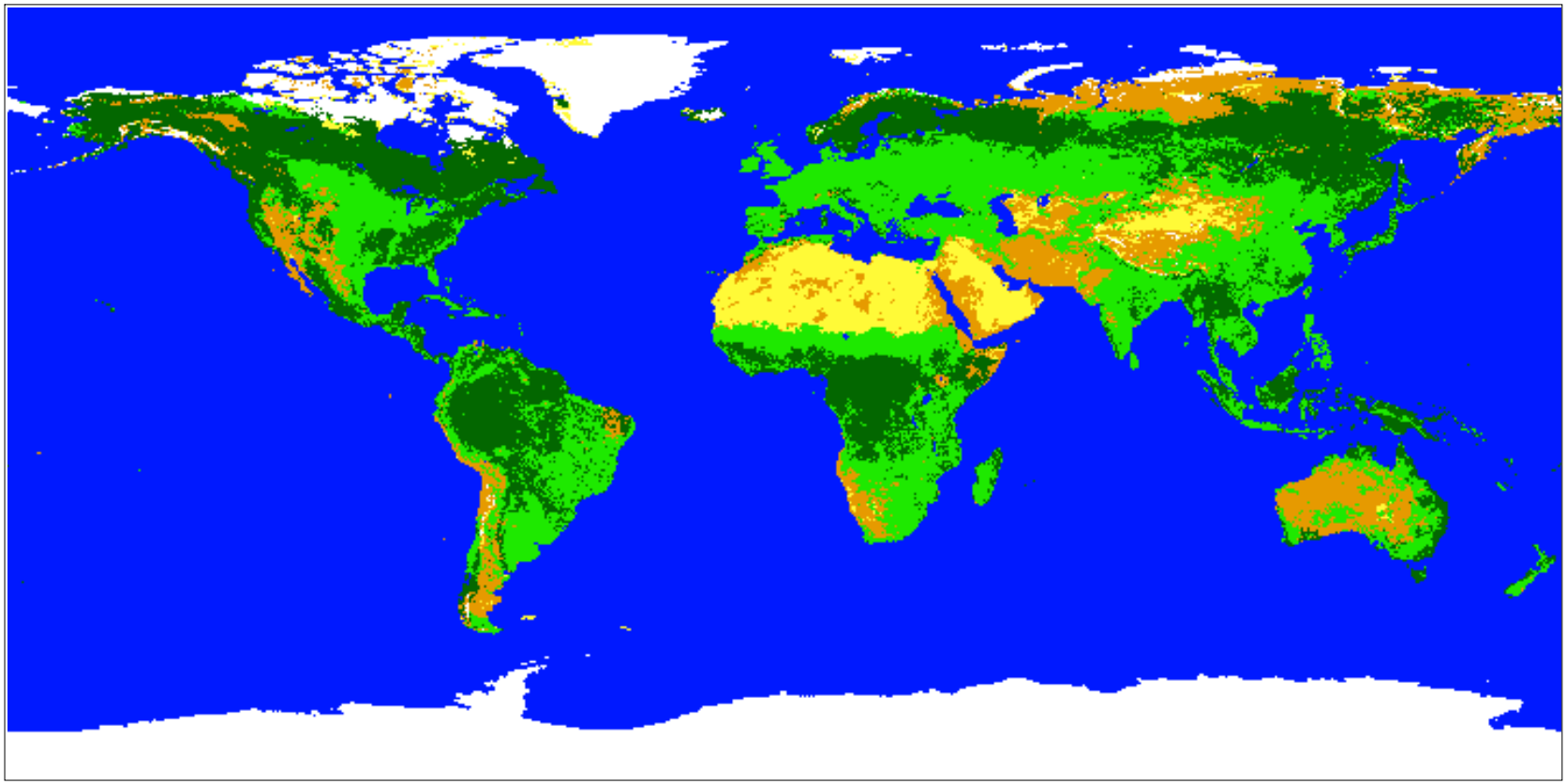
SW ADM Frequency of Occurrence by Cloud Fraction & Cloud Optical Depth (Ocean)

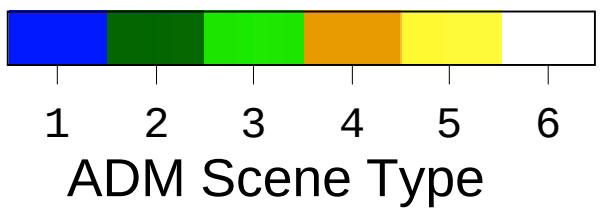


Land and Desert IGBP Type Groupings

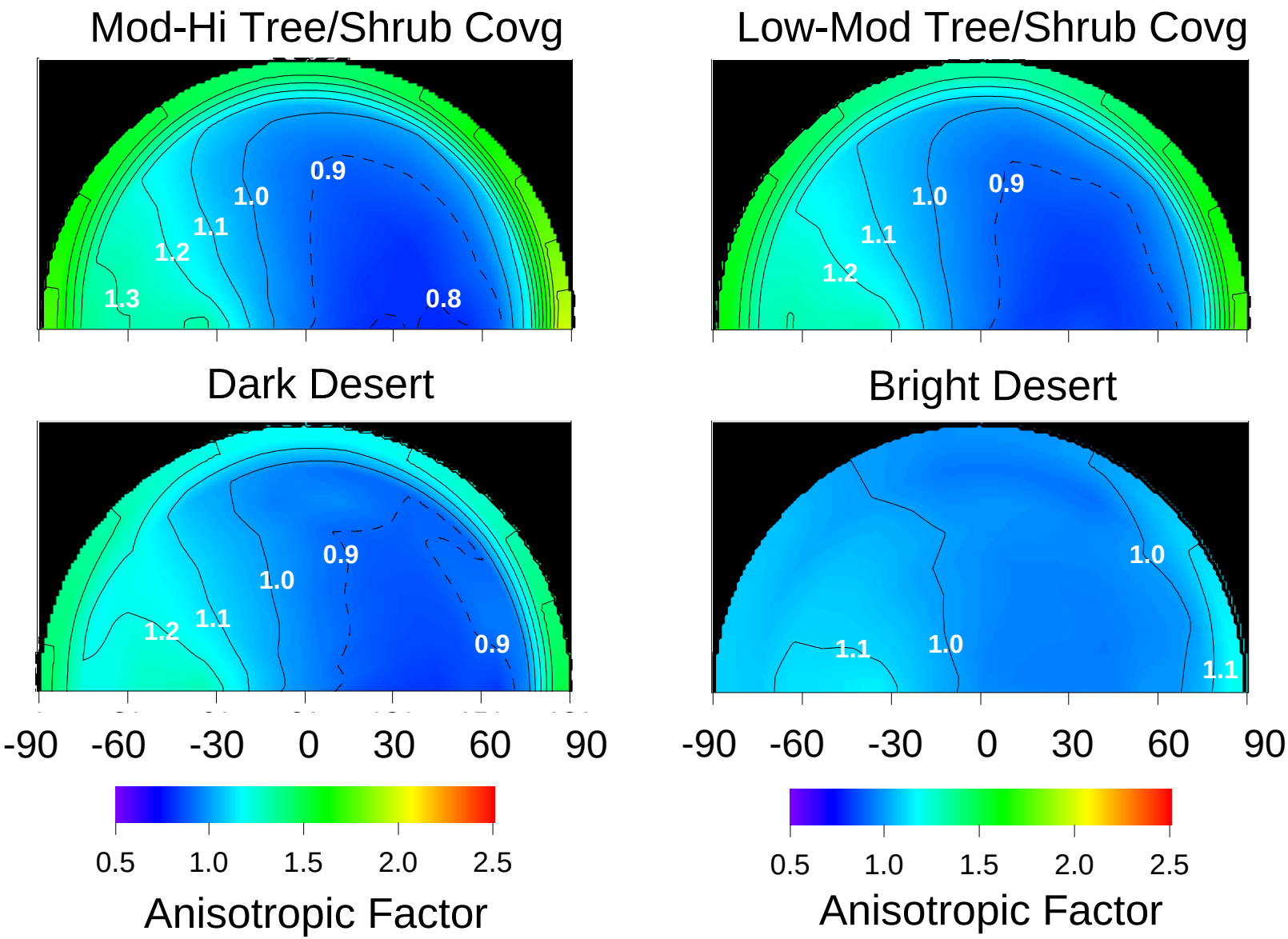


ADM Scene Surface Types

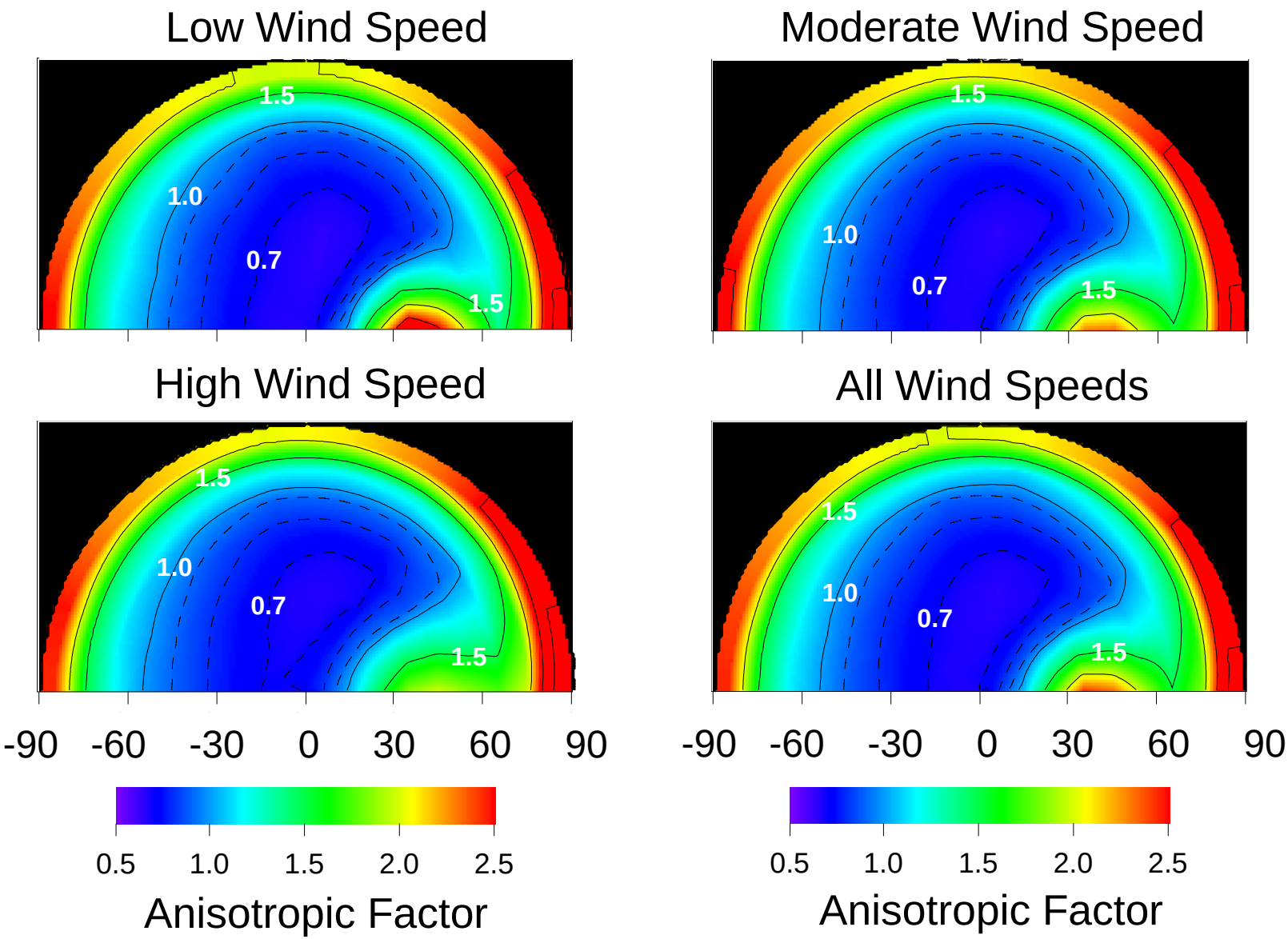




Clear Land and Desert ADMs: θ_o=30°-40°



Clear Ocean ADMs: θ_o=30°-40°



Clear Ocean TOA Flux From CERES

- Define ADMs for 4 discrete wind speed intervals (m s^{-1}):
  < 3.5; 3.5 - 5.5; 5.5 - 7.5; > 7.5

- Estimate instantaneous flux/albedo using ADM:

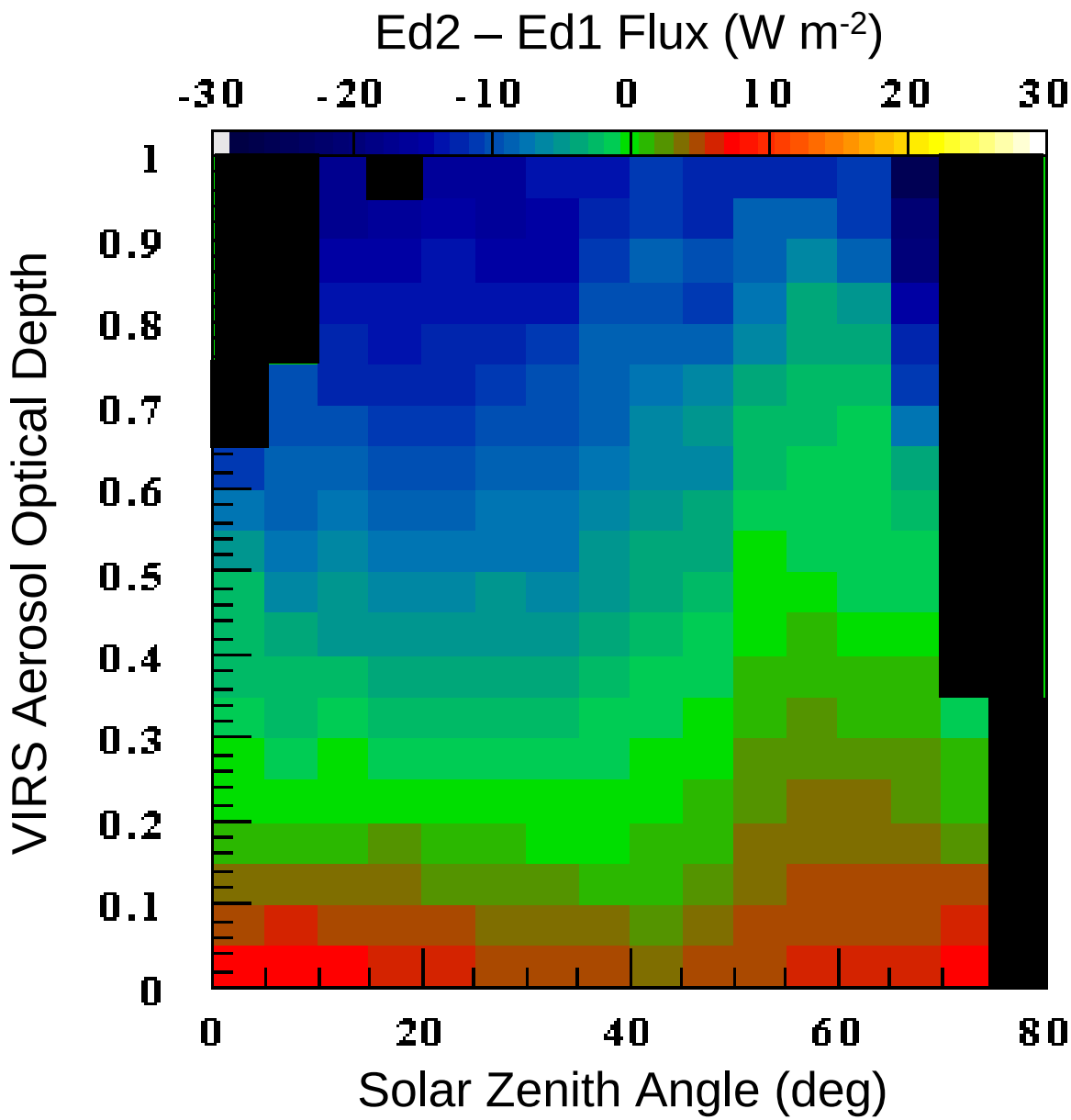
$$\hat{A} = \frac{r(\theta_o, \theta, \phi)}{R_j(w_k, \theta_o, \theta, \phi)}$$

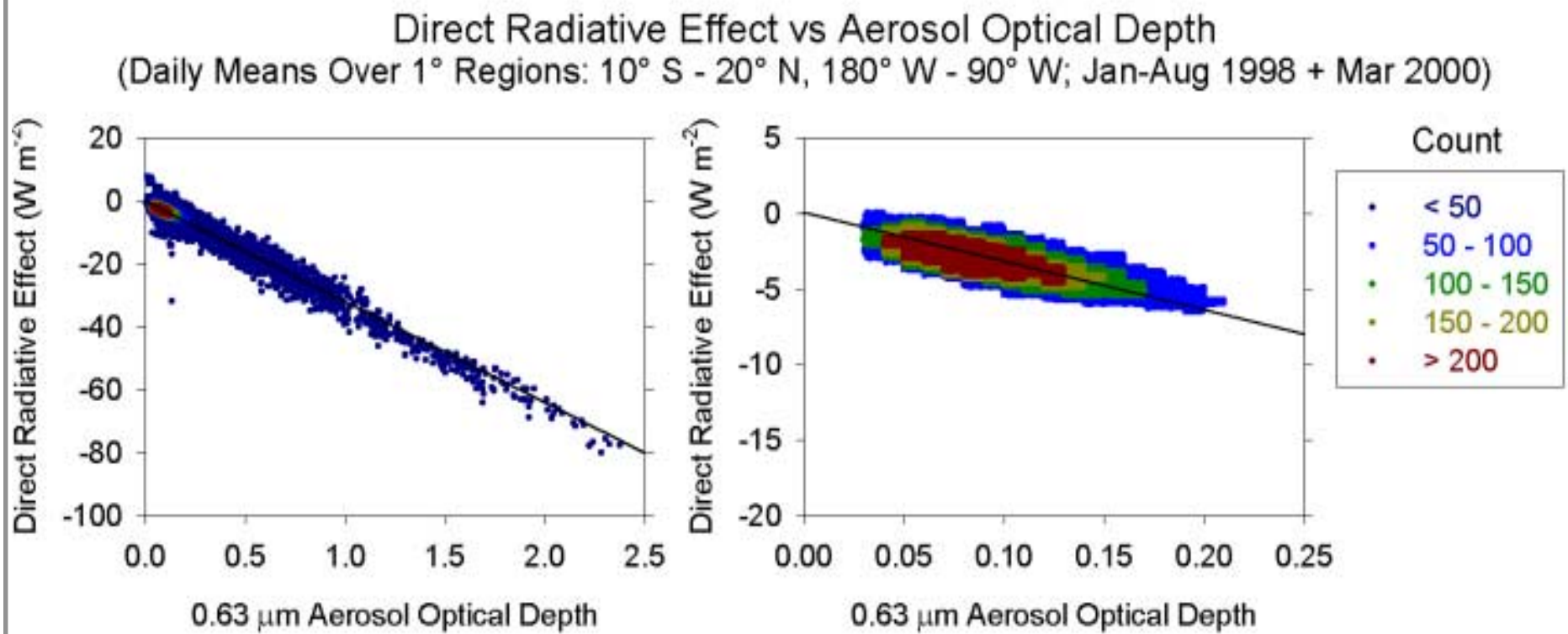
- Account for aerosol optical depth variations theoretically

$$\hat{A}' = \hat{A}\left(\frac{R^{th}(w_k, I^{avg})}{R^{th}(w_k, I^{obs})}\right)$$

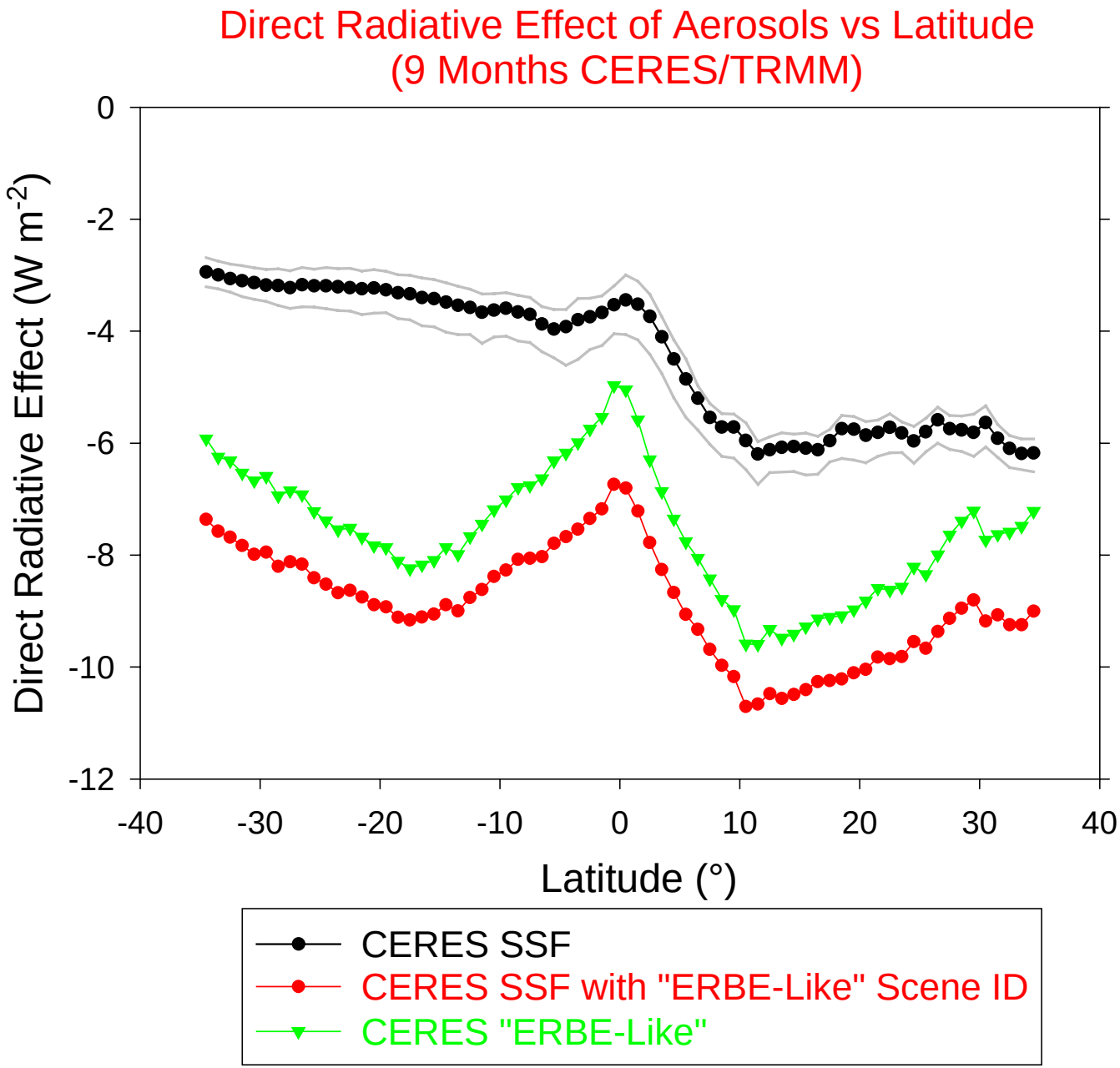
where $R^{th}(w_k, I^{obs})$ is a theoretical anisotropic factor inferred from an instantaneous observation and $R^{th}(w_k, I^{avg})$ is determined from the average radiance used to construct the ADM class.

Clear Ocean Fluxes: Edition 2 vs Edition 1 Flux



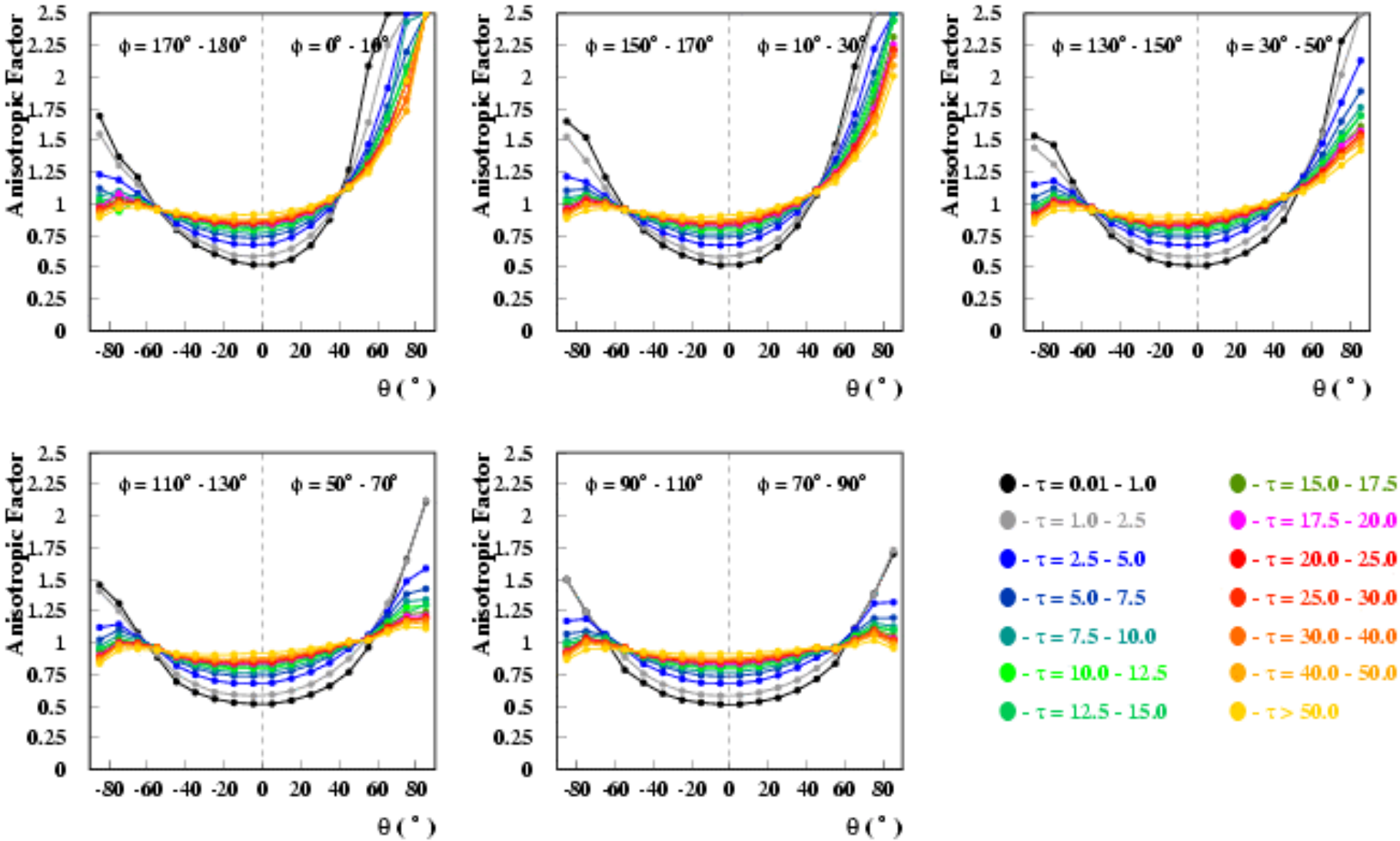


Loeb and Kato, 2001 (*J. Climate*, Submitted)



Loeb and Kato, 2001 (*J. Climate*, submitted)

Ocean Cloud ADMs, f = 99.9 - 100, Ice, θ_o = 60 - 70 °

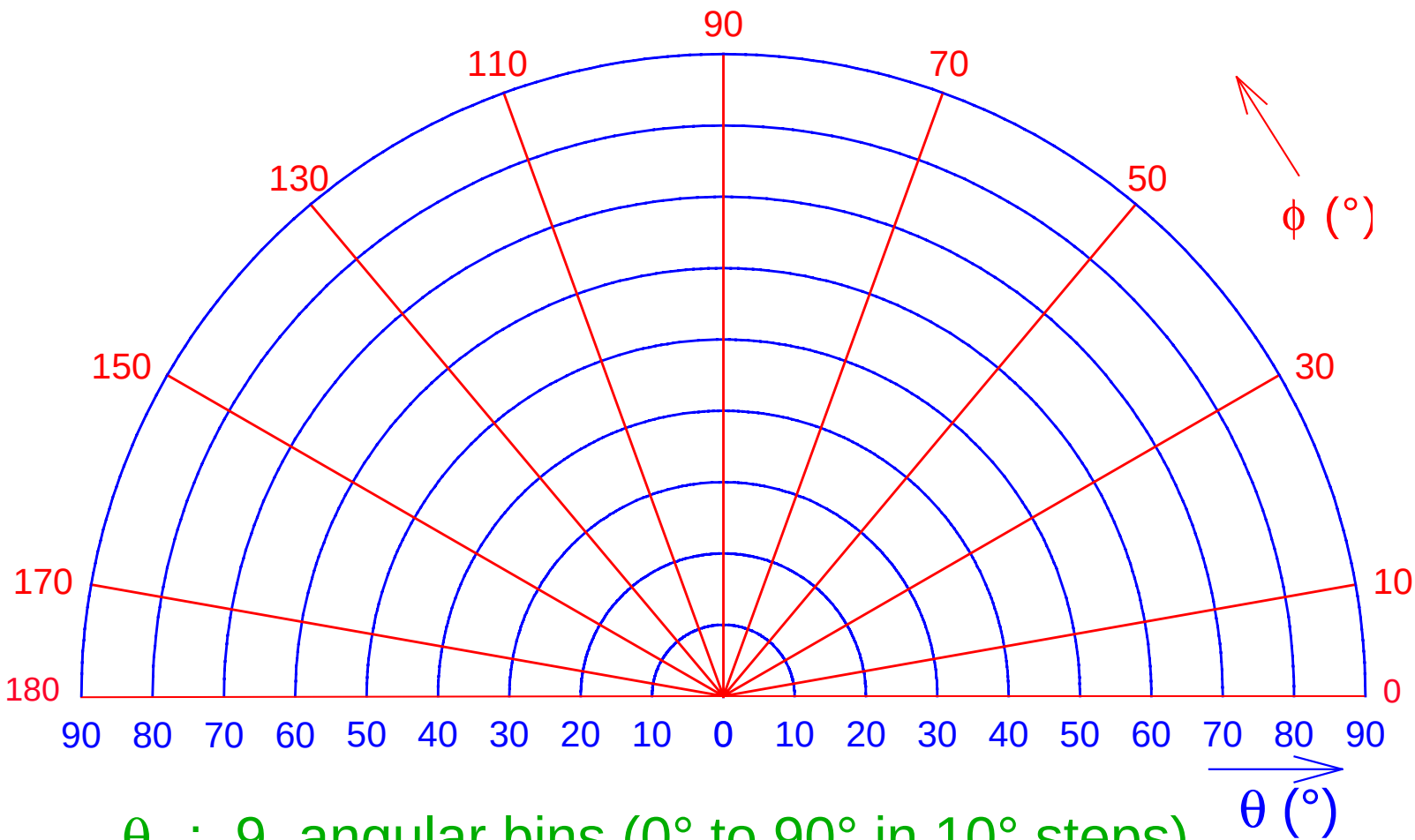


SW TOA Flux Validation

- Does mean all-sky flux depend on viewing geometry?
- Comparisons with Direct Integration Fluxes:
  - Solar zenith angle dependence (SW)
  - Latitudinal dependence
  - Regional fluxes

- Instantaneous Flux Uncertainties
  - Use alongtrack data to examine consistency of incident fluxes from the same scene

CERES SW ADM Angular Bin Definitions



θ_o : 9 angular bins (0° to 90° in 10° steps)

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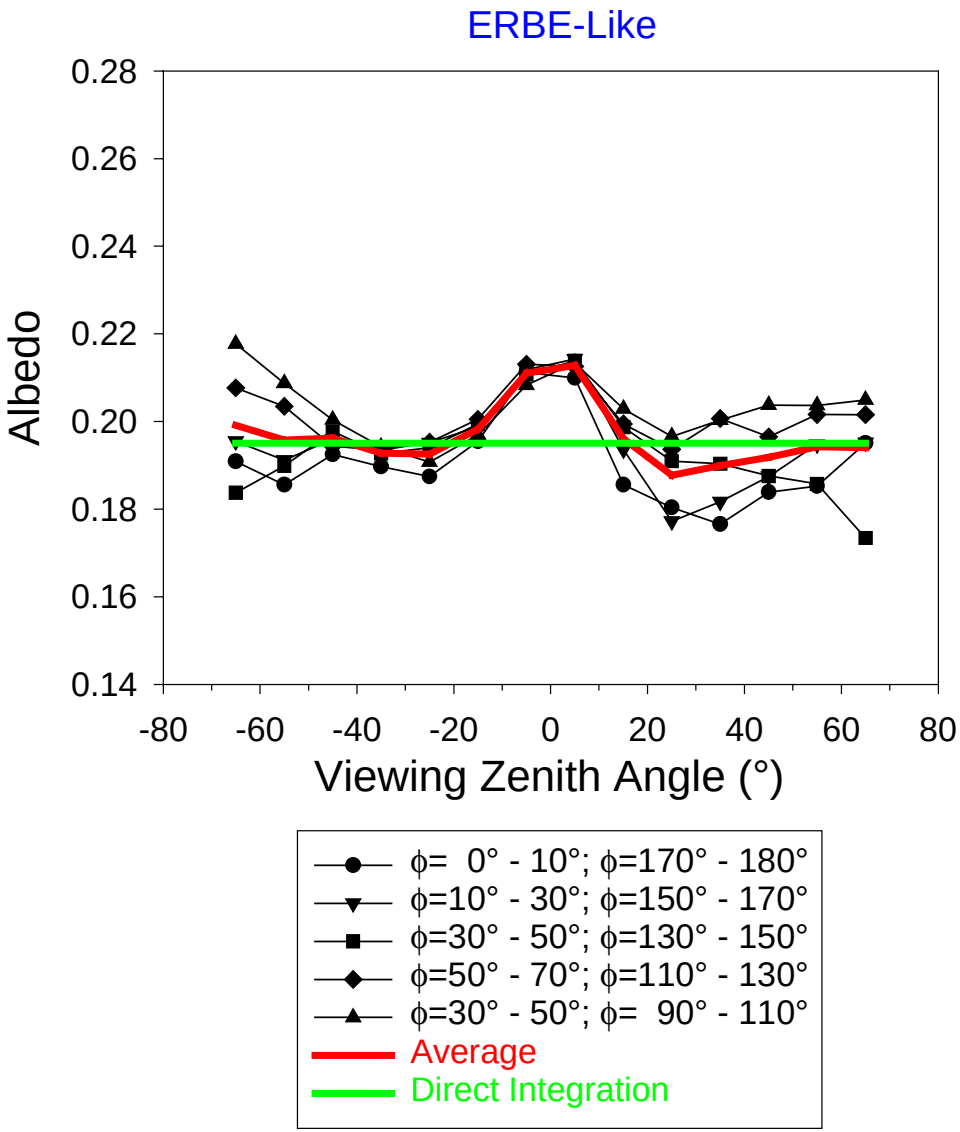
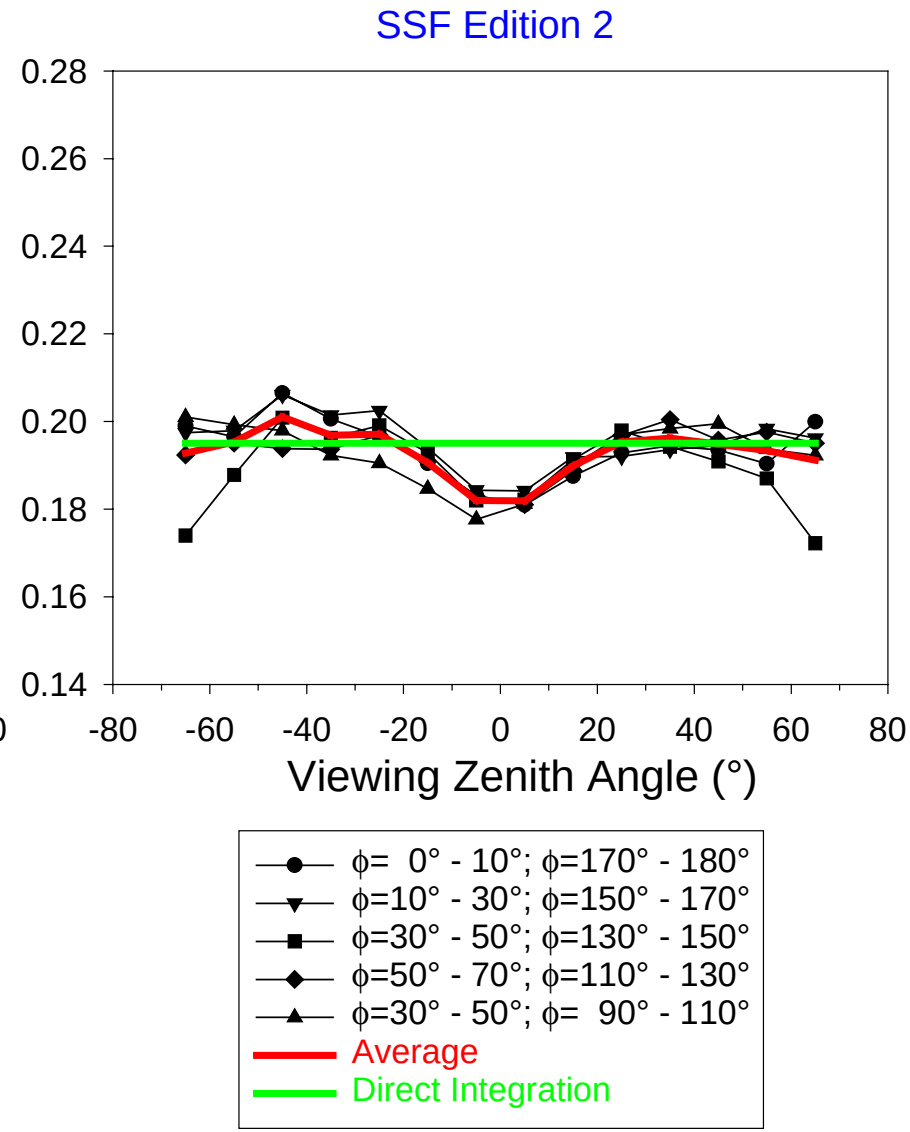
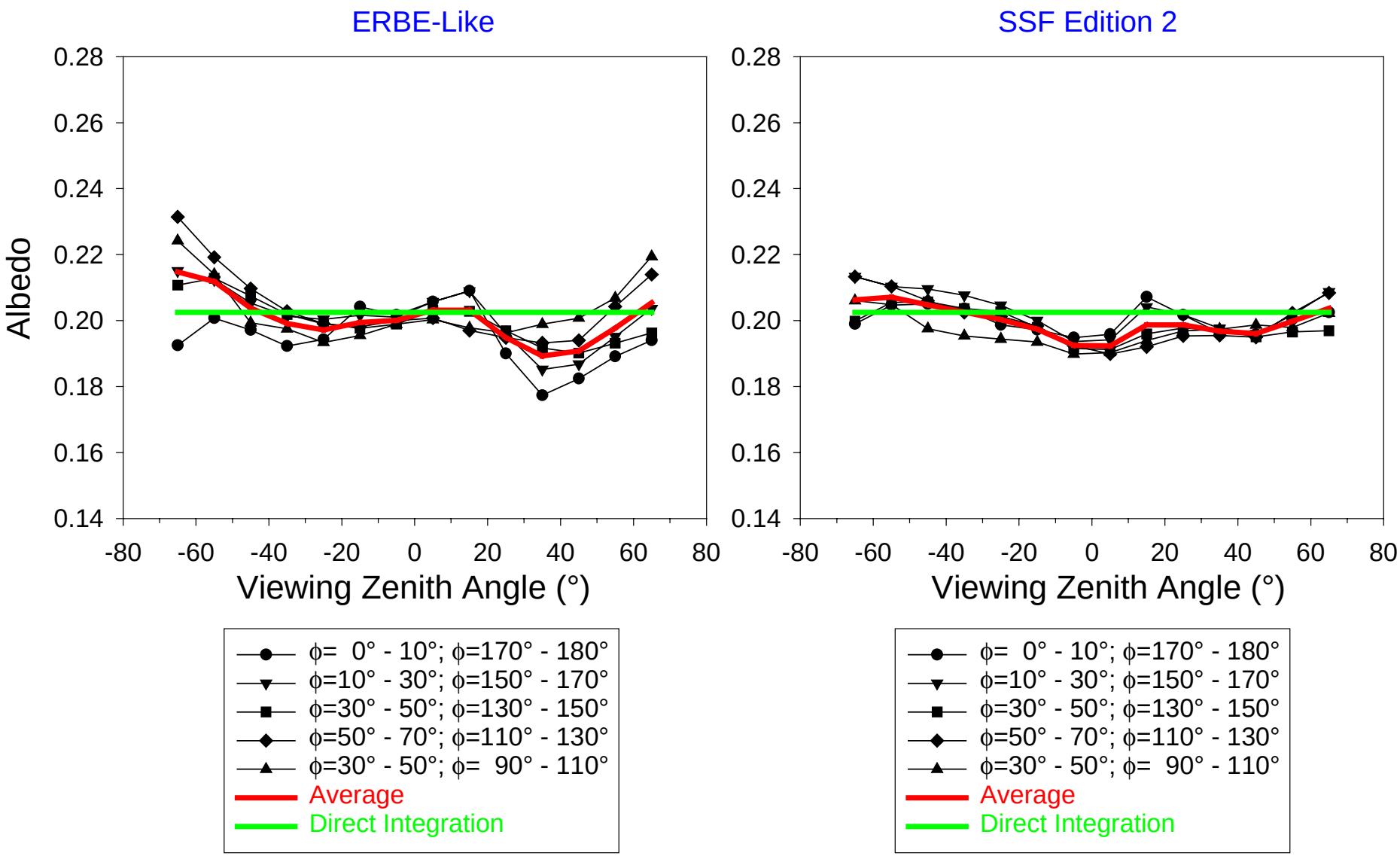
All-Sky Albedo: Solar Zenith Angle = 0° - 10°

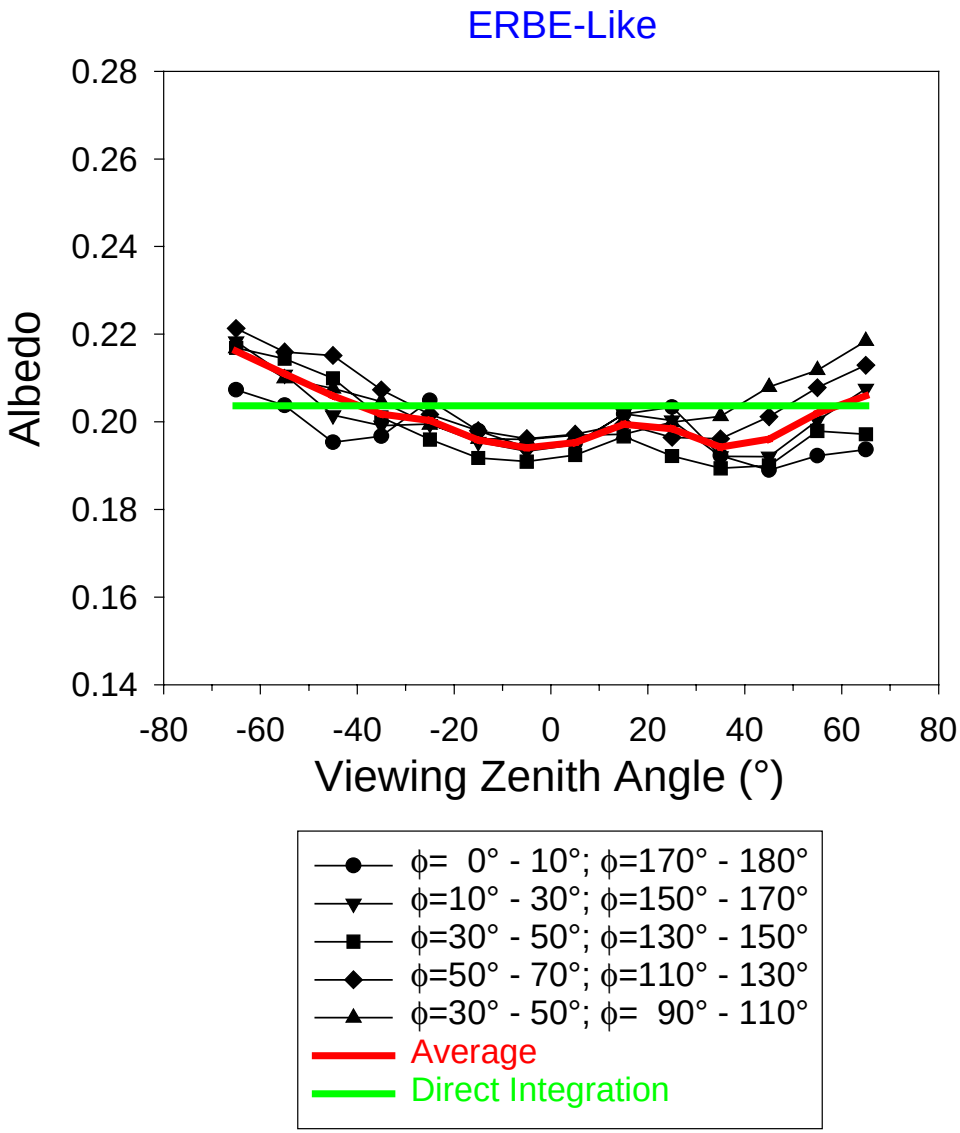


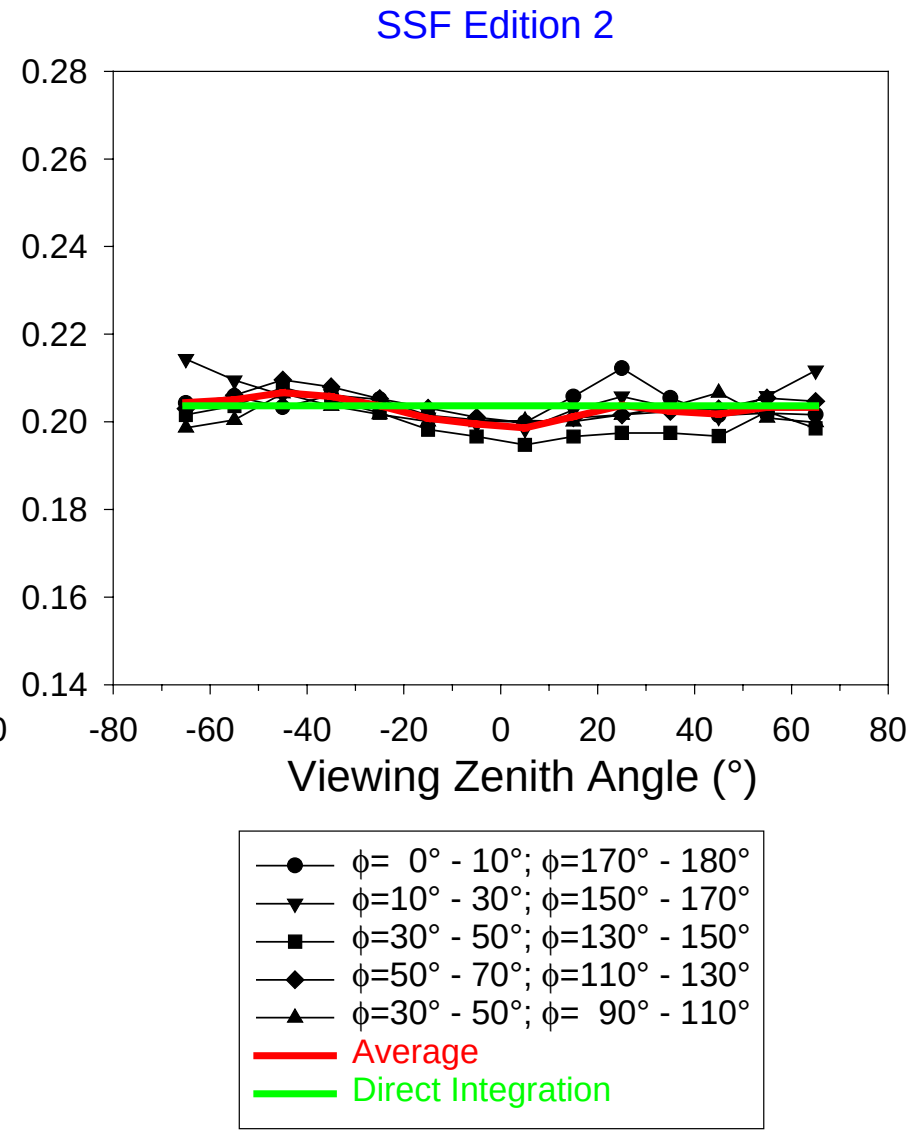


All-Sky Albedo: Solar Zenith Angle = 10° - 20°

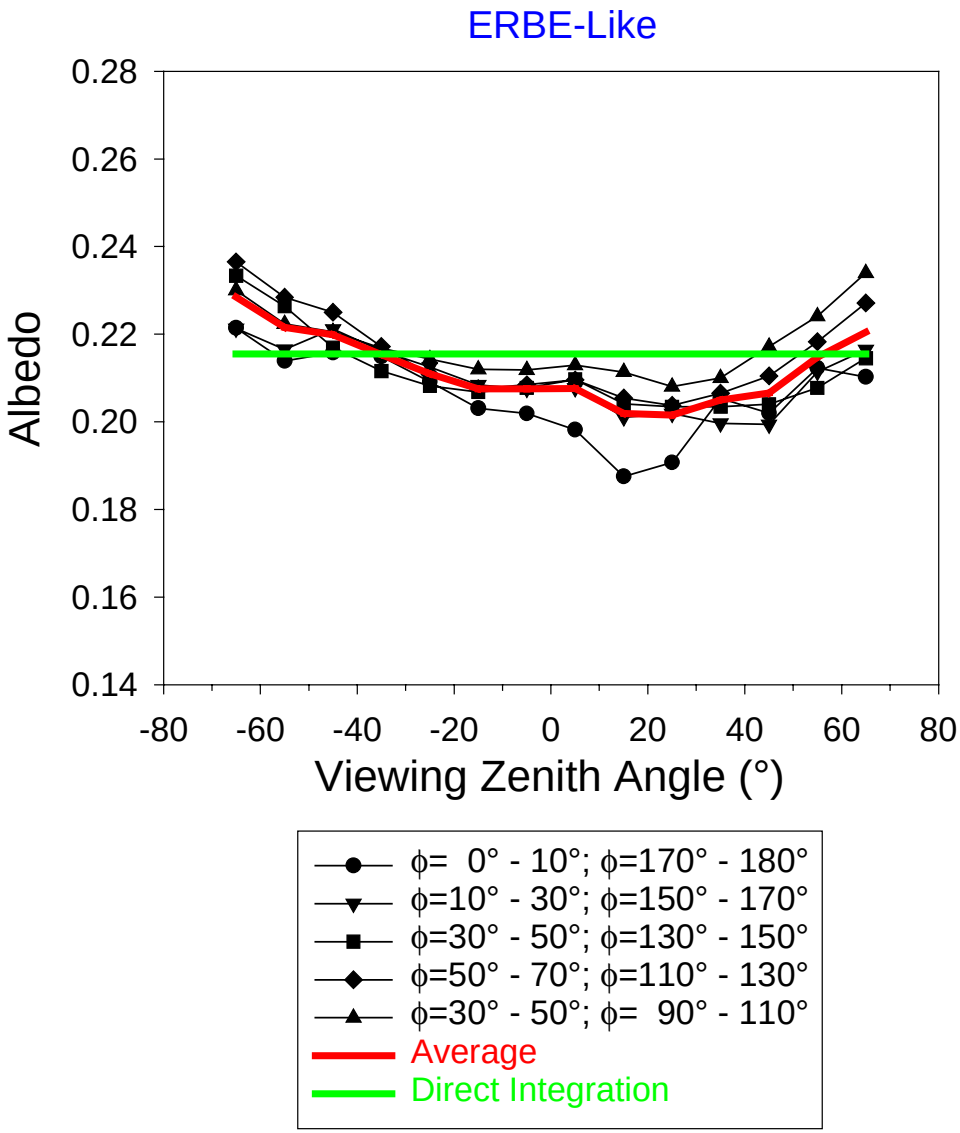


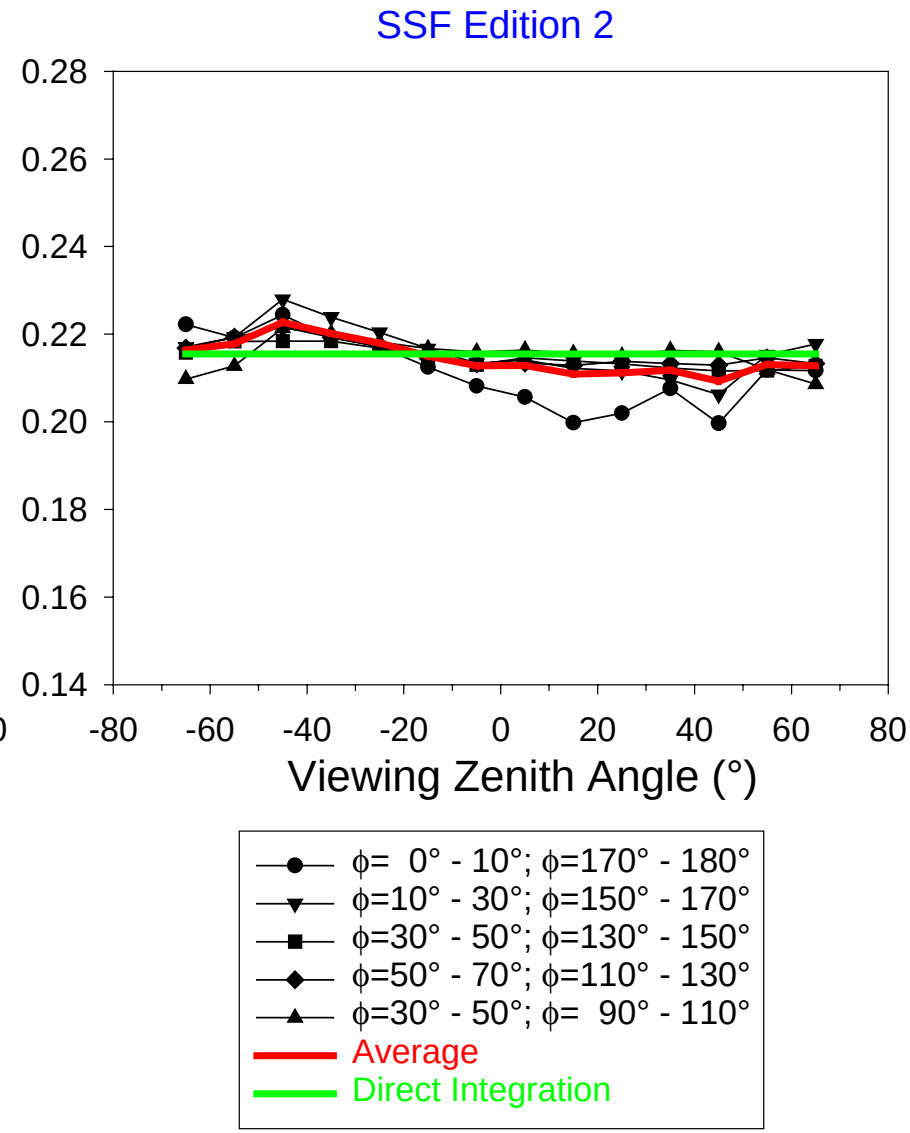
All-Sky Albedo: Solar Zenith Angle = 20° - 30°



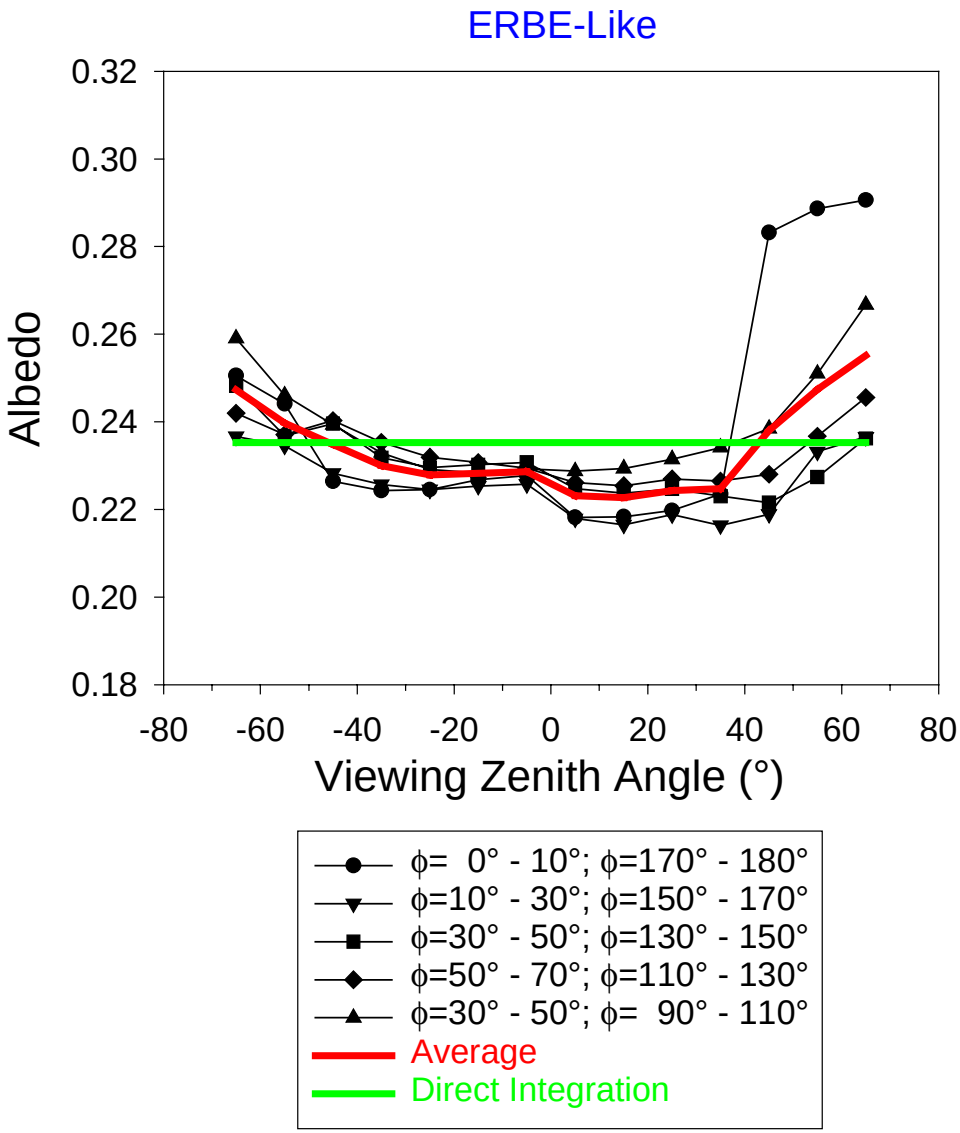


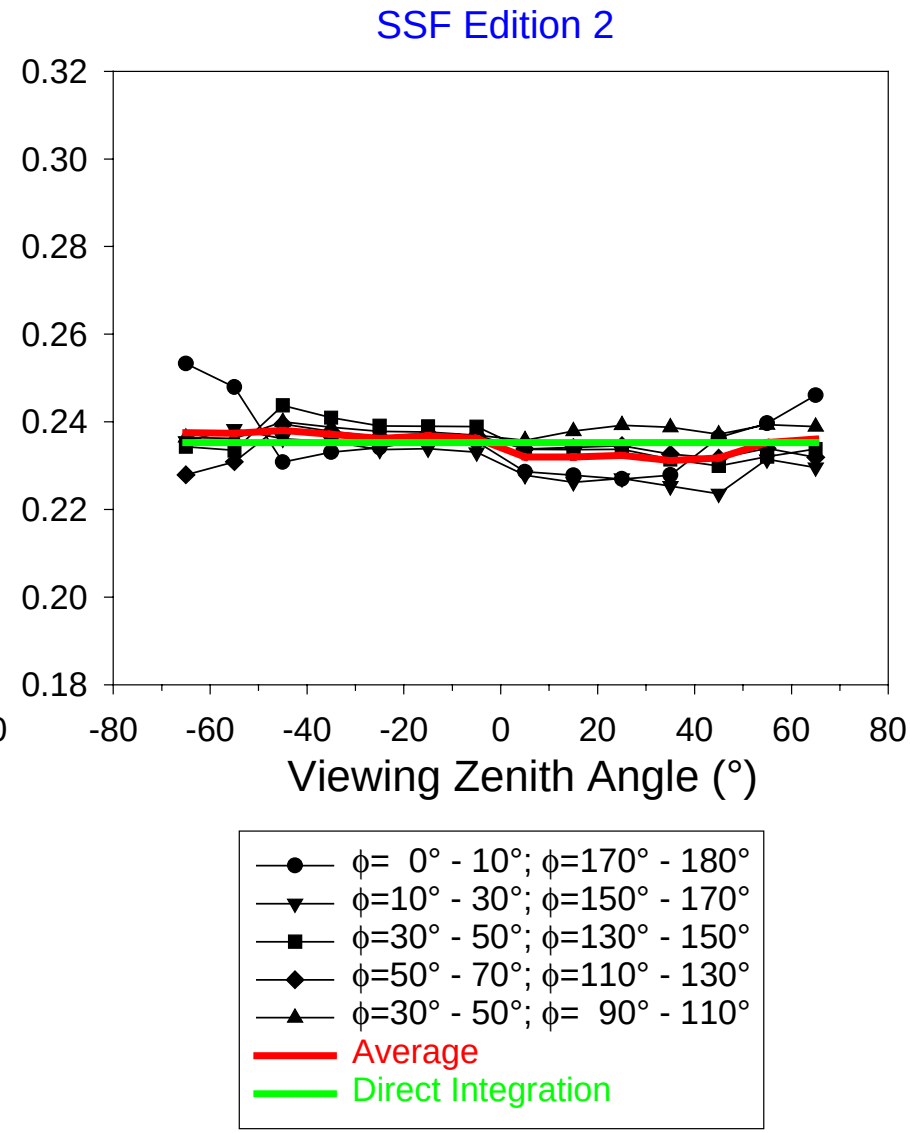
All-Sky Albedo: Solar Zenith Angle = 30° - 40°



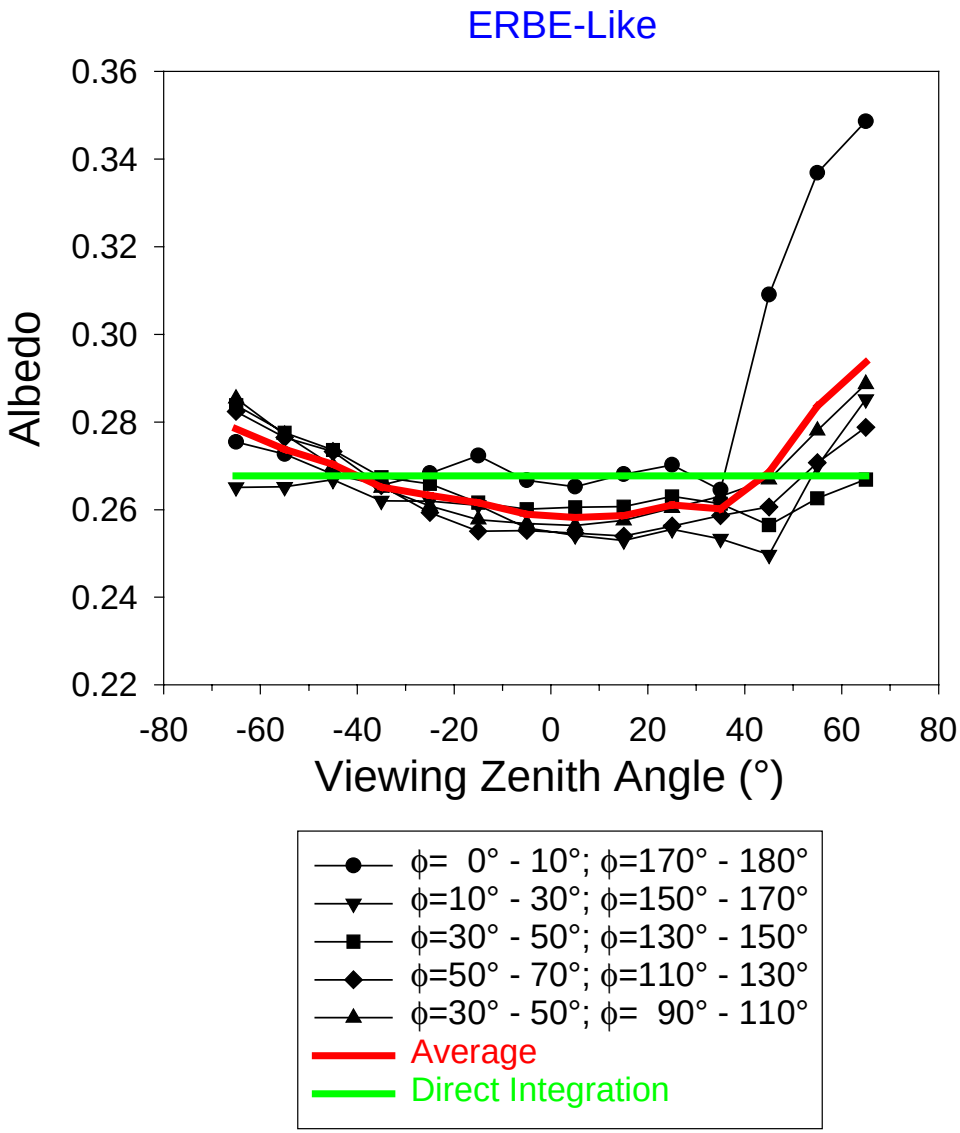


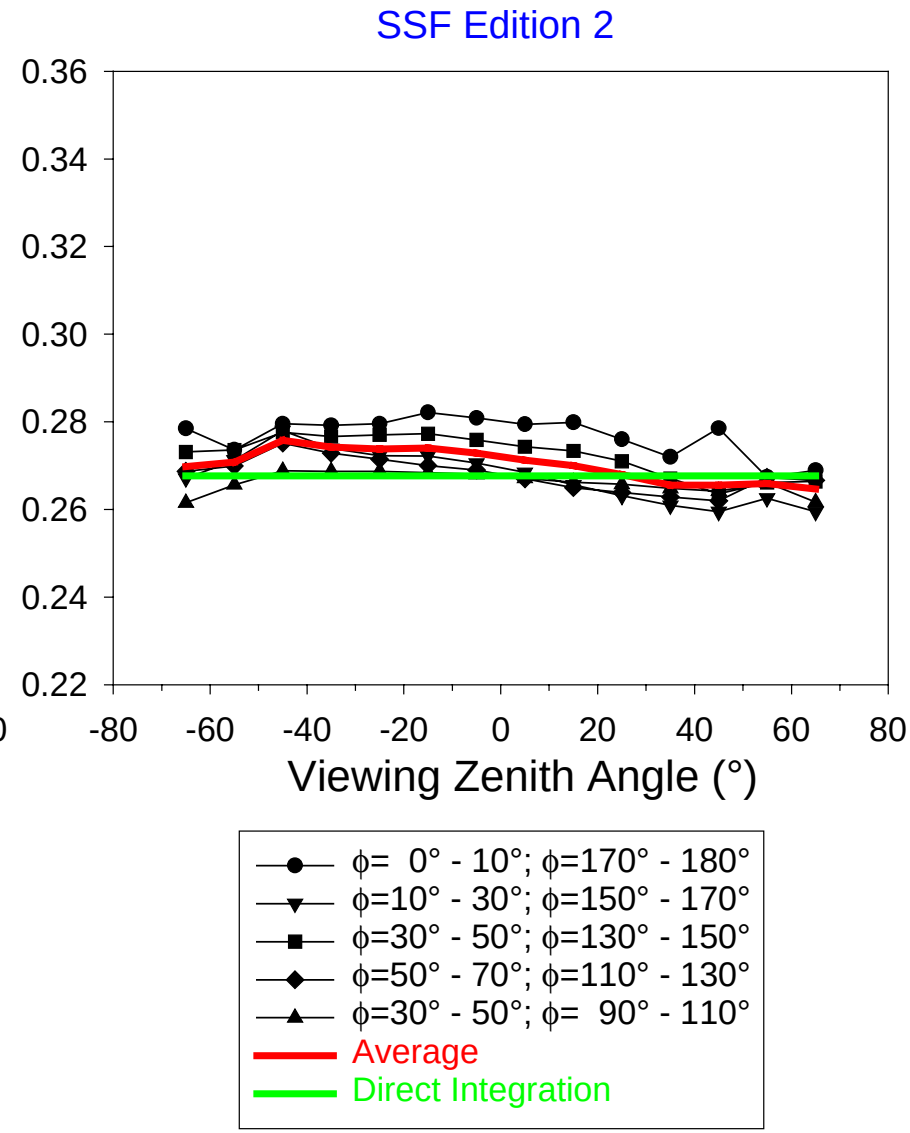
All-Sky Albedo: Solar Zenith Angle = 40° - 50°



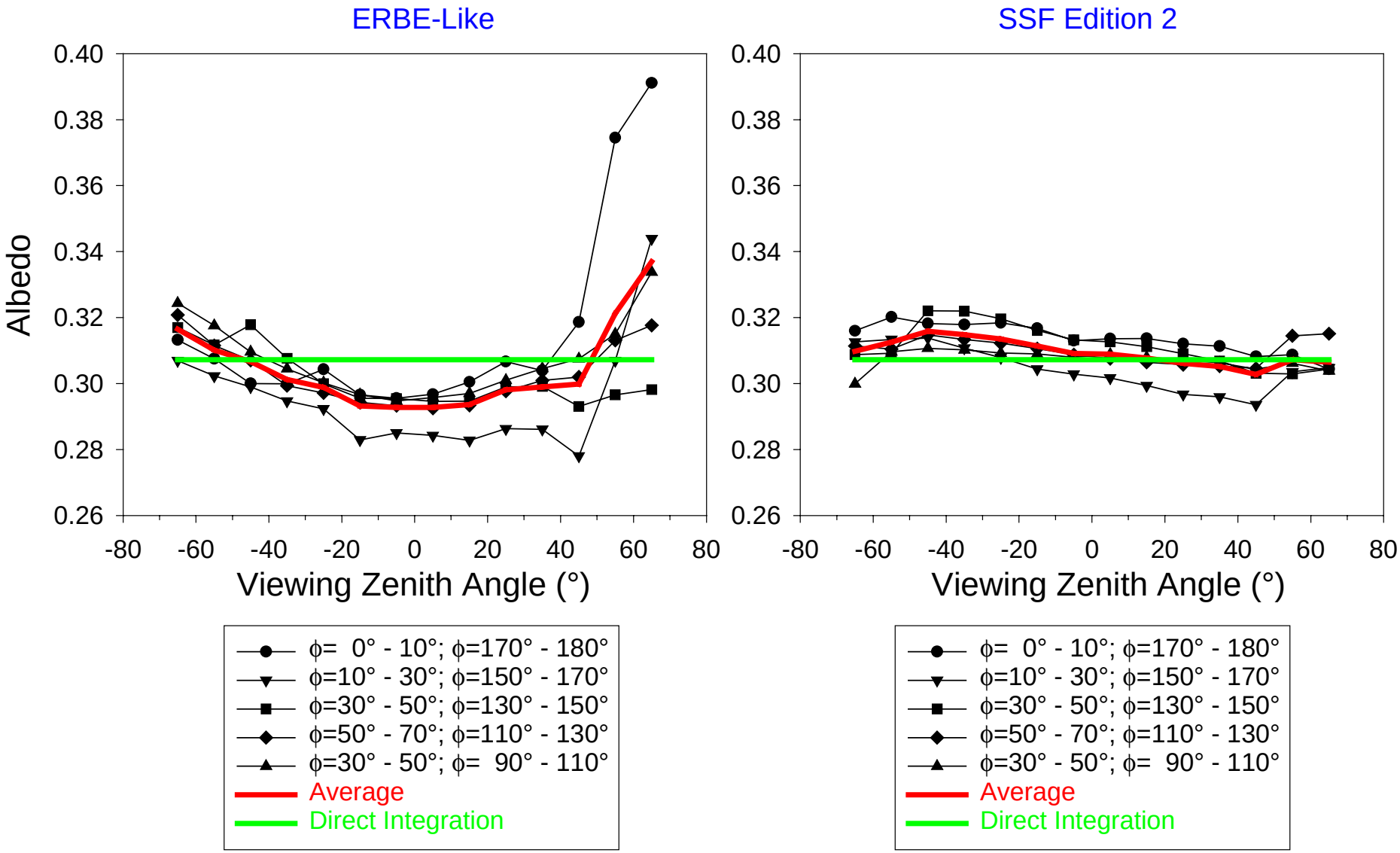


All-Sky Albedo: Solar Zenith Angle = 50° - 60°

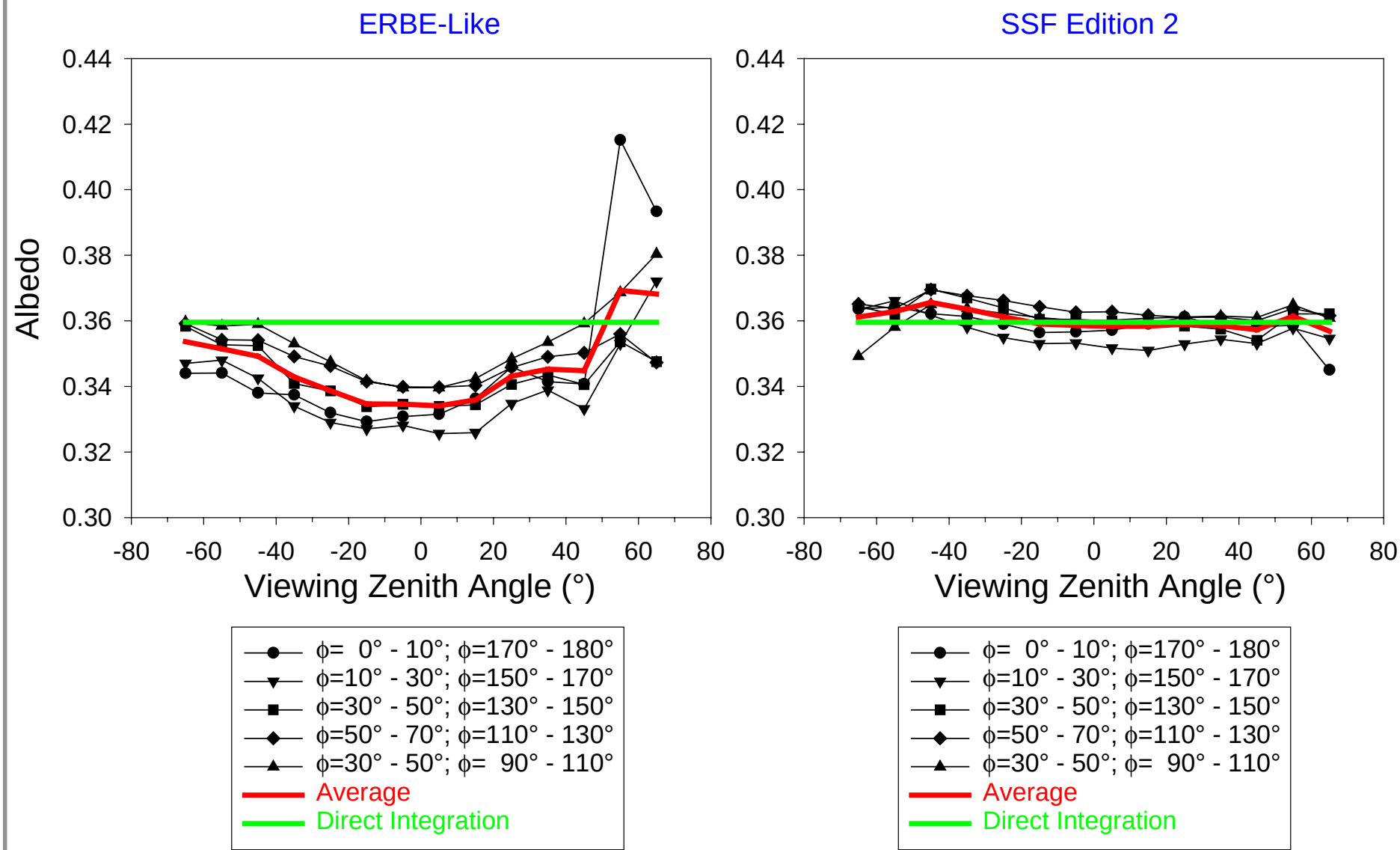




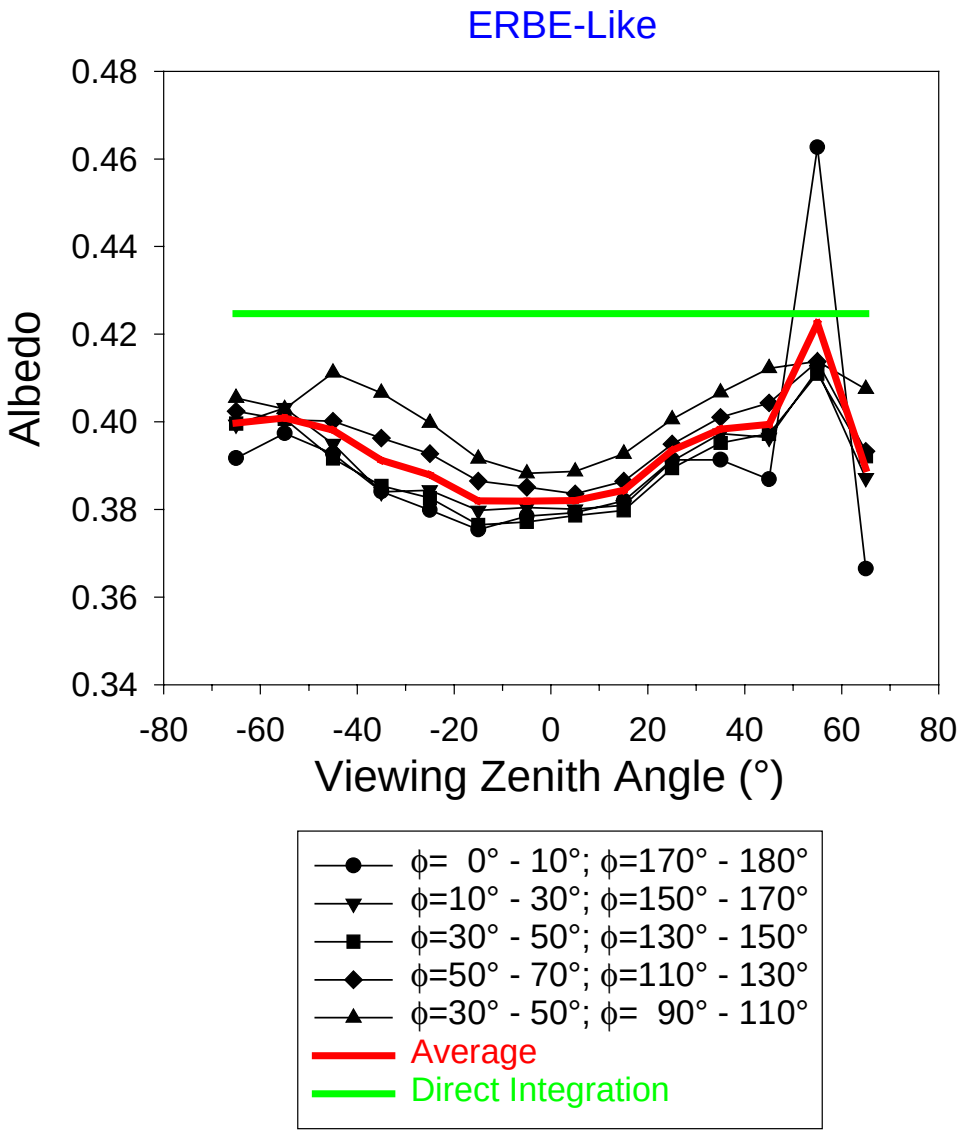
All-Sky Albedo: Solar Zenith Angle = 60° - 70°

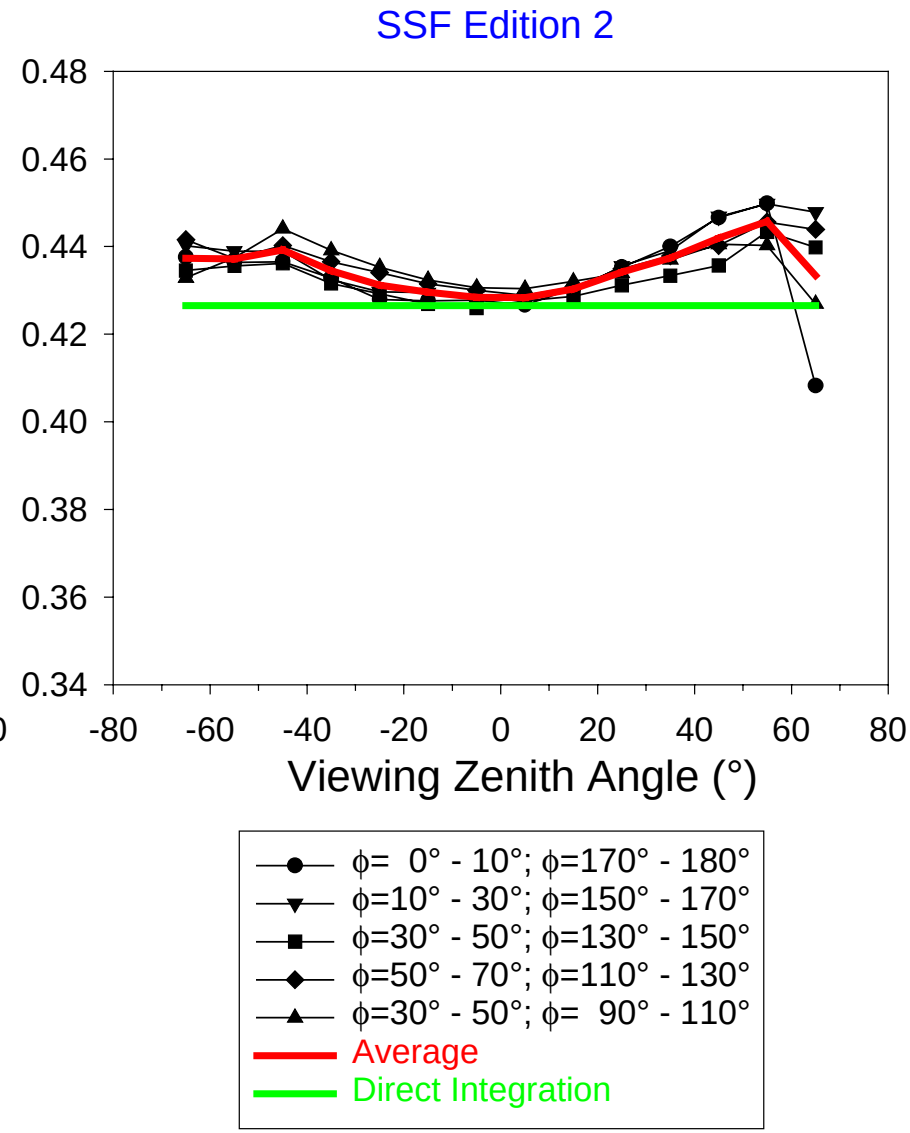


All-Sky Albedo: Solar Zenith Angle = 70° - 80°



All-Sky Albedo: Solar Zenith Angle = 80° - 90°





Flux Bias Definitions

- ADM mean flux bias in angular bin ($\theta_o, \theta_j, \phi_k$) :

$$\Delta(\theta_o, \theta_j, \phi_k) = \overline{F}_{ADM}(\theta_o, \theta_j, \phi_k) - F_{DI}(\theta_o)$$

- Footprint-weighted ADM mean flux bias:

$$\Delta_\Omega(\theta_o) = \frac{1}{n_k}\frac{1}{n_j}\sum_{k=1}^{n_k}\sum_{j=1}^{n_j}\Delta(\theta_o, \theta_j, \phi_k) w_j$$

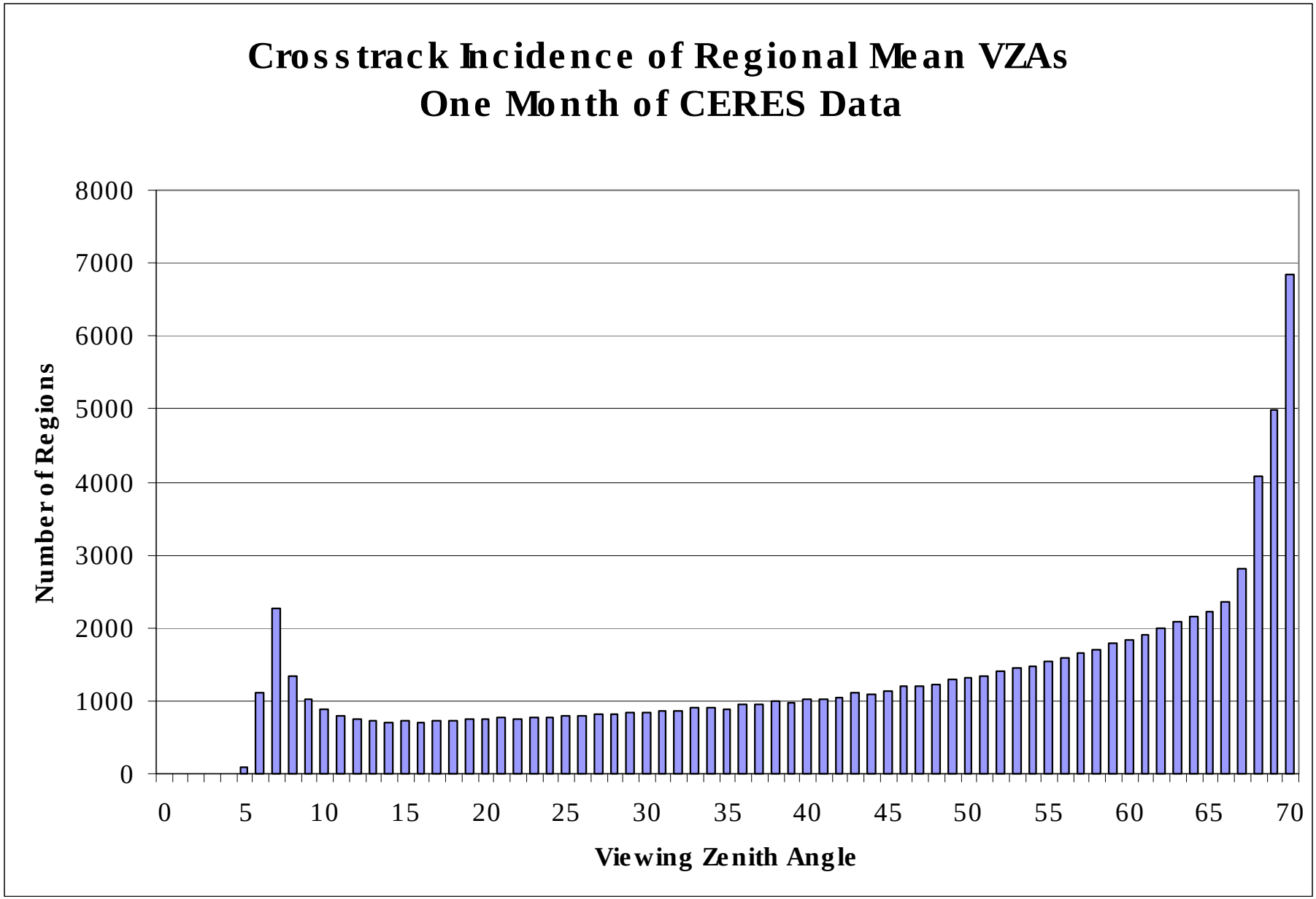
where w_j is a weighting factor accounting for the relative effect of different viewing zenith angles on gridded time-averaged fluxes.

n_k and n_j are the number of relative azimuth and viewing zenith angle bins.

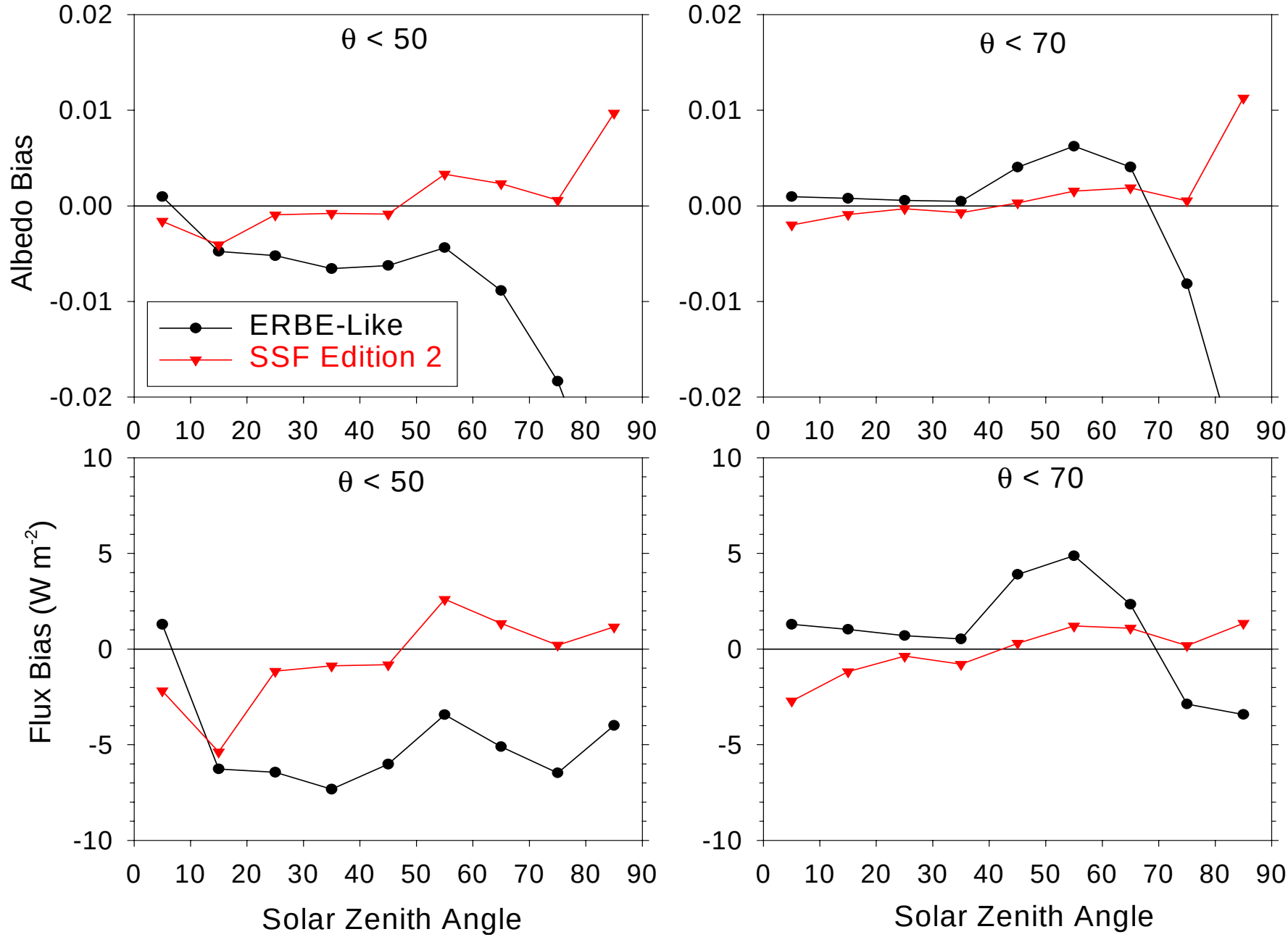
- Standard deviation in footprint-weighted ADM flux bias:

$$\sigma_\Omega(\theta_o) = \sum_{k=1}^{n_k}\sum_{j=1}^{n_j}\frac{[\Delta(\theta_o, \theta_j, \phi_k) - \overline{\Delta}(\theta_o)]^2}{(n_k n_j - 1)} w_j$$

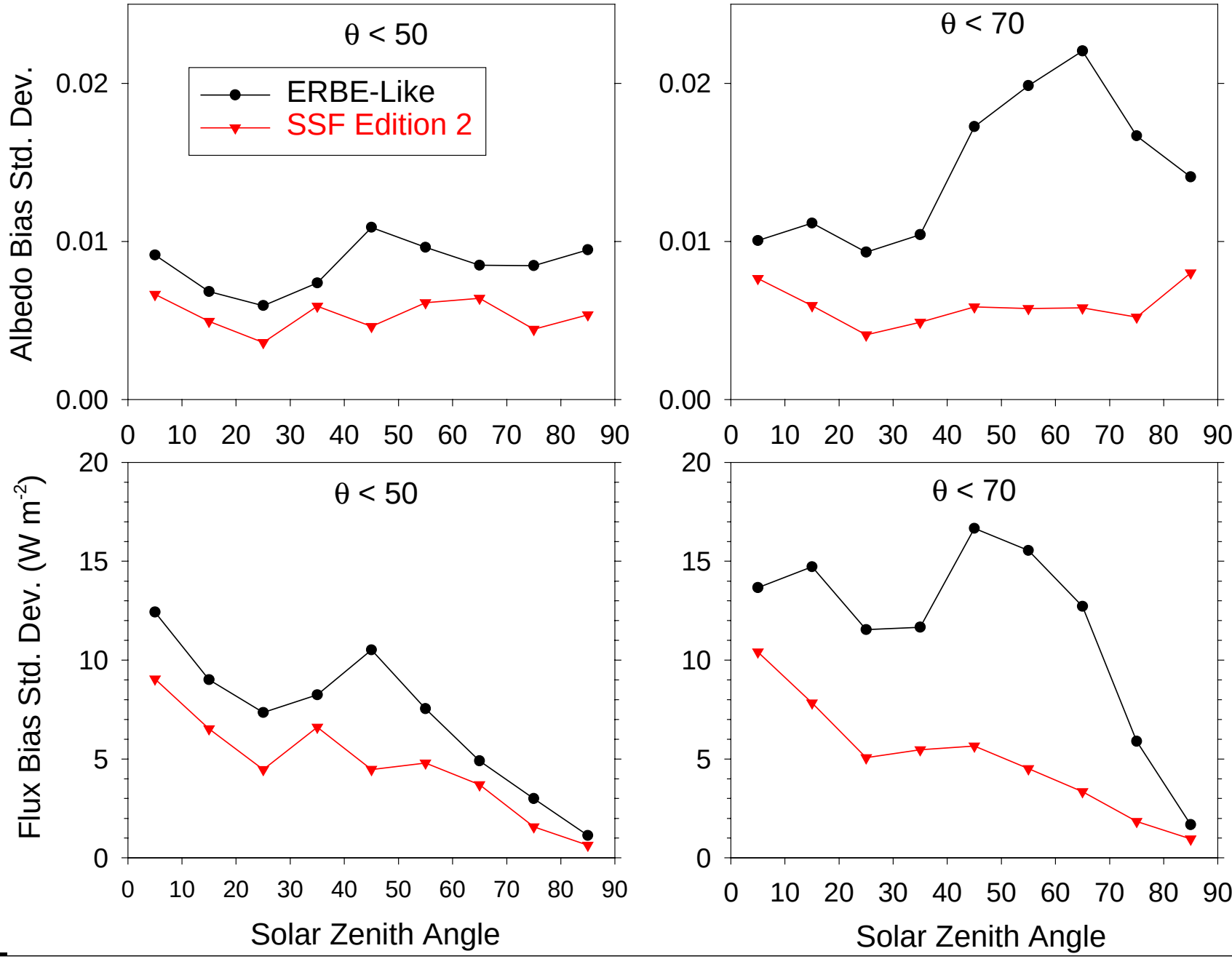
$\Rightarrow$ measure of consistency in ADM mean flux estimate from individual viewing directions.


Crosstrack Incidence of Regional Mean VZAs
One Month of CERES Data
Number of Regions
8000
7000
6000
5000
4000
3000
2000
1000
0
0
5
10
15
20
25
30
35
40
45
50
55
60
65
70
Viewing Zenith Angle

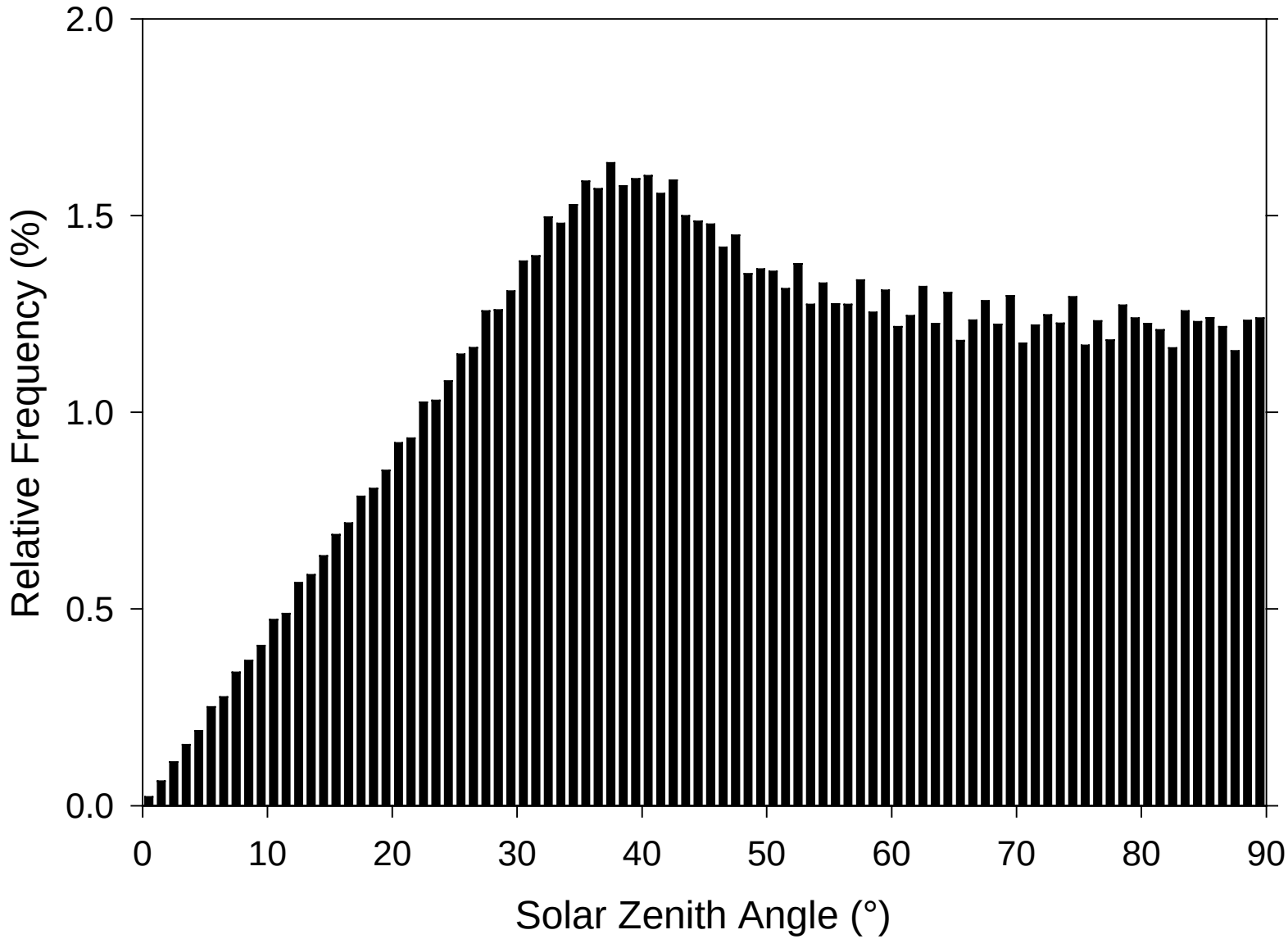
Footprint-Weighted All-Sky Mean Albedo and Flux Bias vs θ_o



Std. Dev. in Footprint-Wtd All-Sky Albedo and Flux Bias vs θ_o



Solar Zenith Angle Relative Frequency (40°S - 40°N; March 1998)

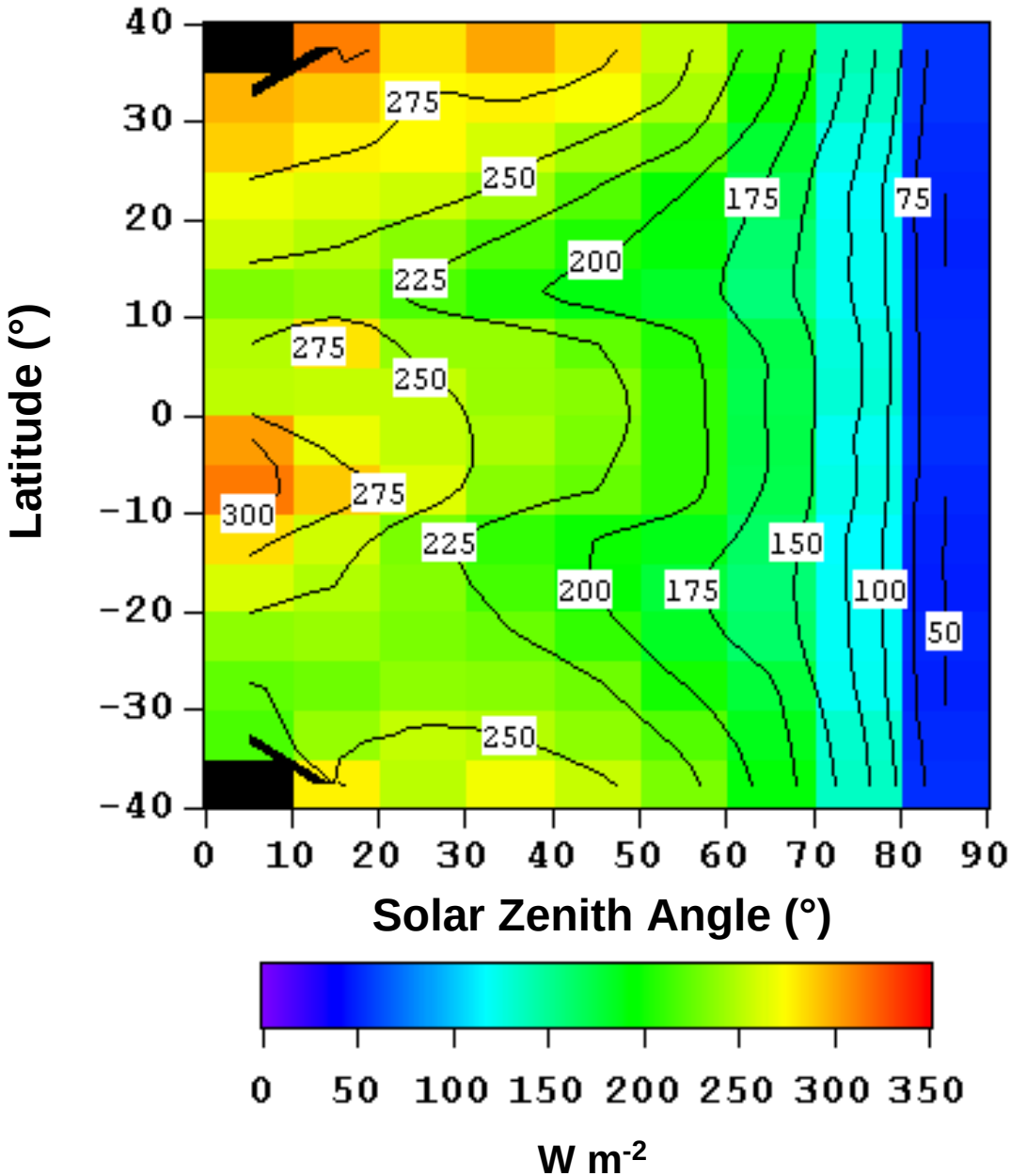


Tropical ADM Mean Flux Bias

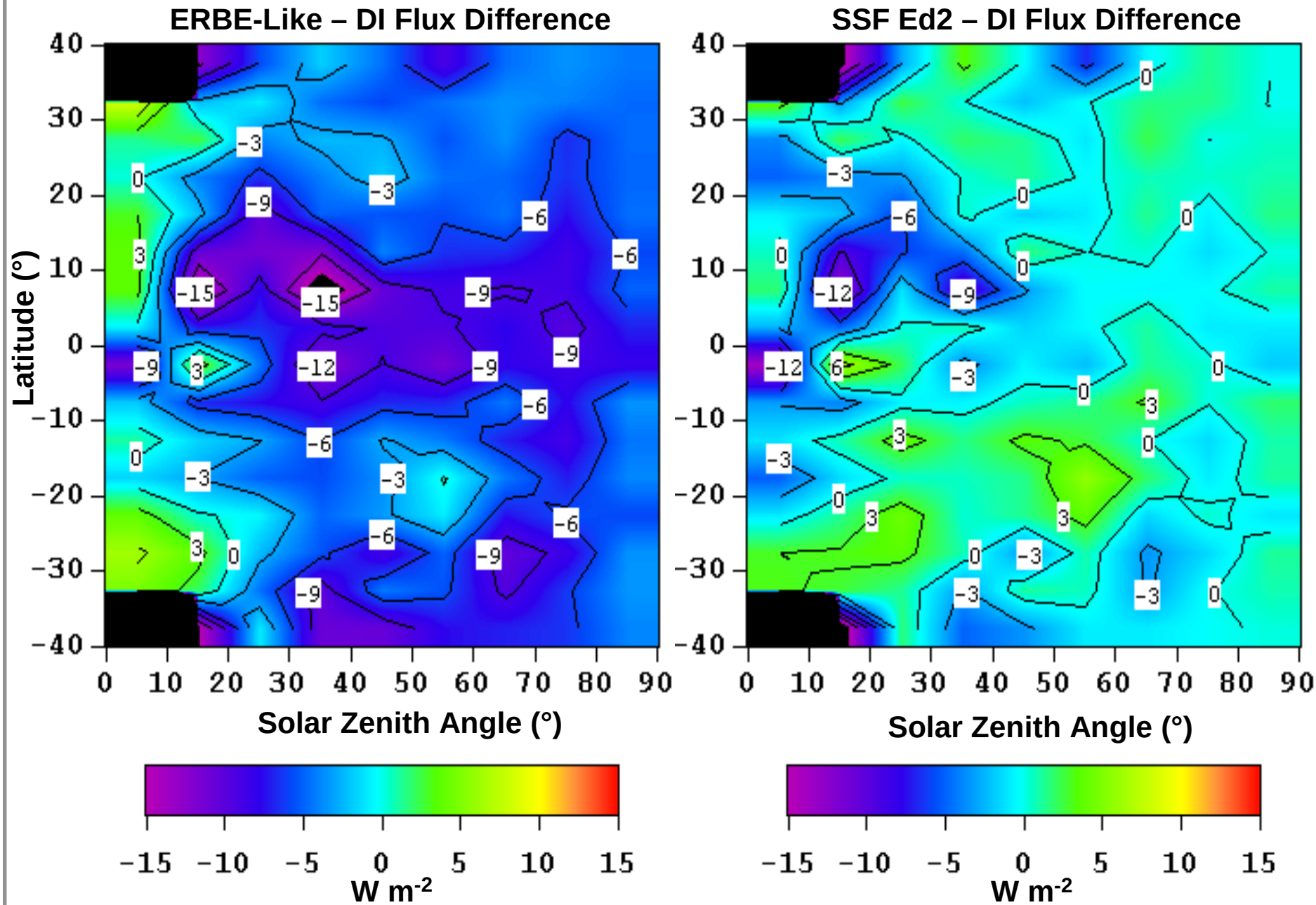
(Footprint-Weighted; March 1998 Solar Zenith Angle Sampling)

($W\ m^{-2}$)	ERBE-Like		SSF Edition 2	
θ-Range	Mean (Δ_Ω)	Std (σ_Ω)	Mean (Δ_Ω)	Std (σ_Ω)
$\theta < 50°$	-2.7	3.3	-0.05	2.1
$\theta < 70°$	0.50	5.6	0.11	2.2

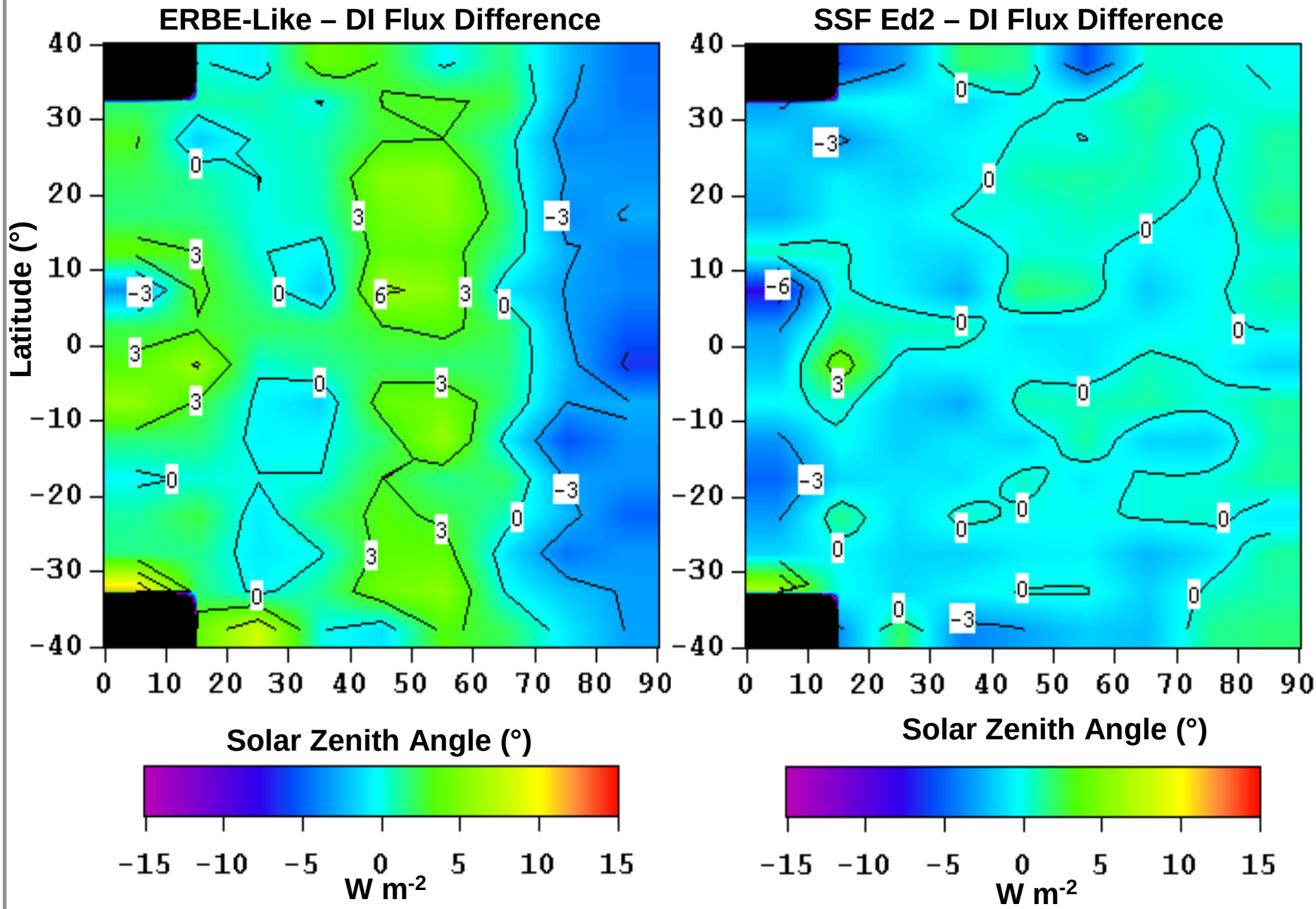
All-Sky Direct Integration Flux by Latitude & Solar Zenith Angle



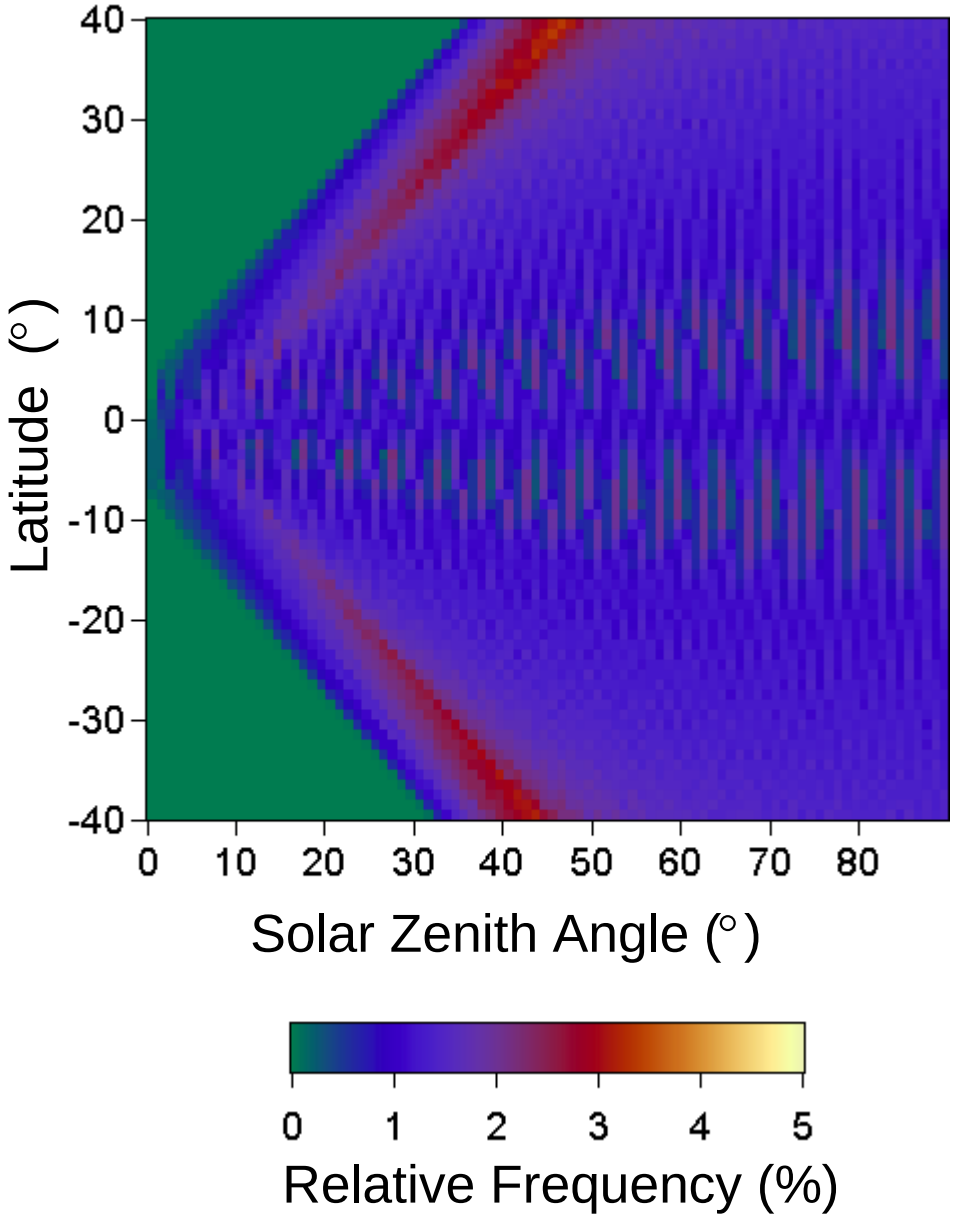
All-Sky Flux Difference ($\theta < 50°$)



All-Sky Flux Difference ($\theta < 70°$)

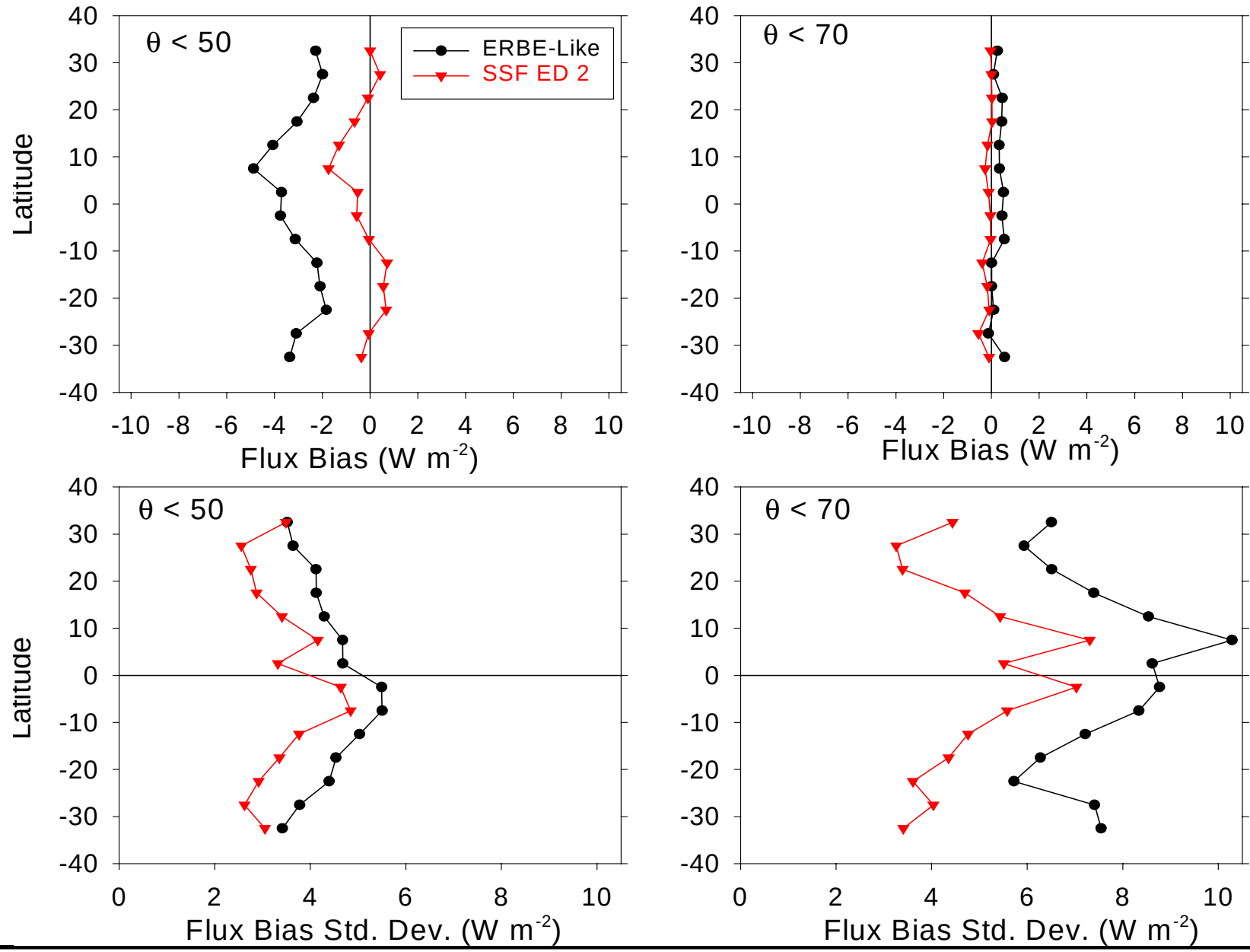


Solar Zenith Angle Distribution by Latitude (March 1998)



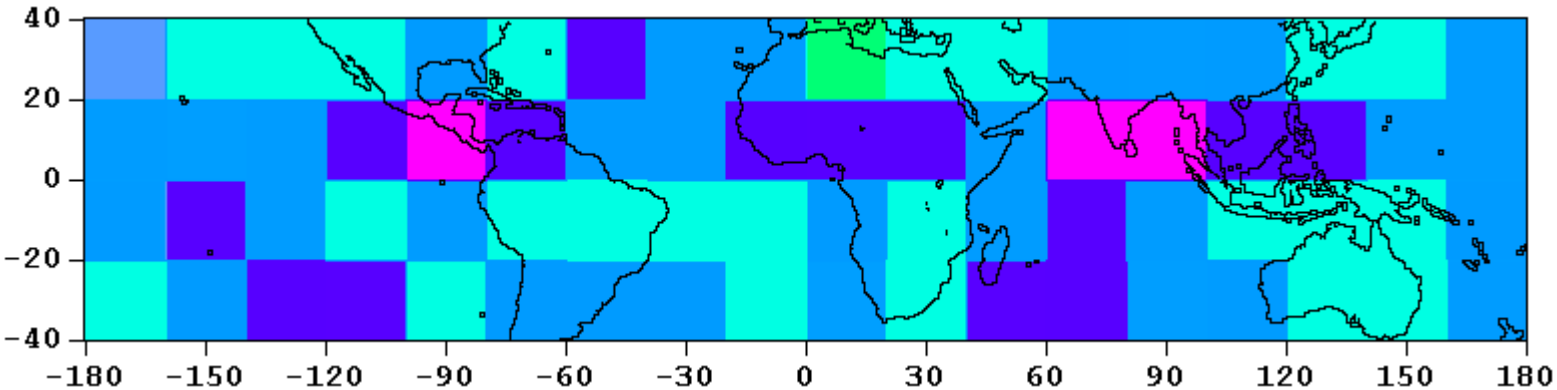
Latitudinal ADM Mean Flux Bias

(March 1998 Solar Zenith Angle Sampling)

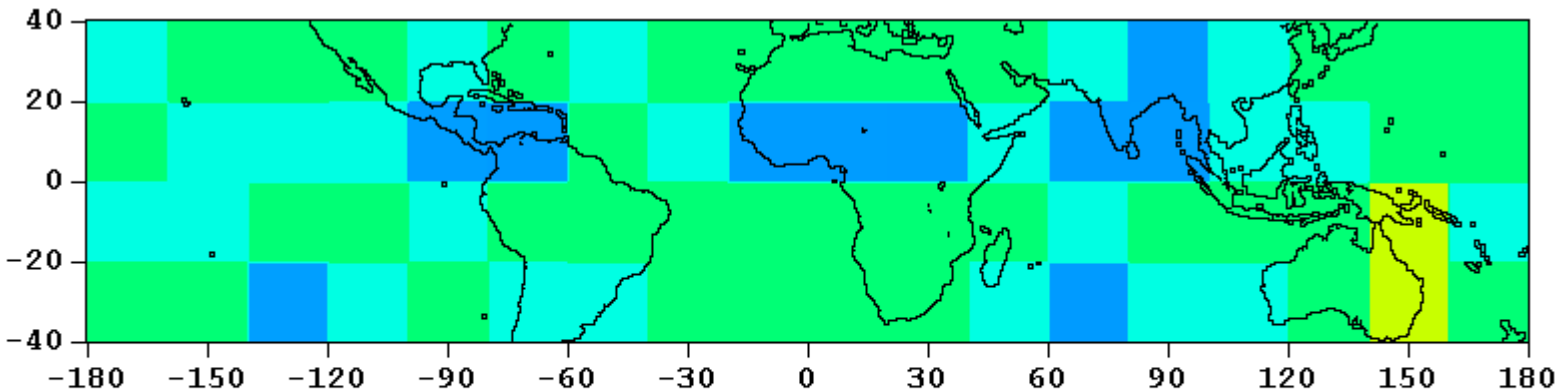


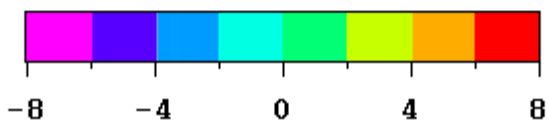
ADM Mean Regional Flux Biases ($\theta < 50°$)

ERBE-Like – DI Flux Difference



SSF Ed2 – DI Flux Difference

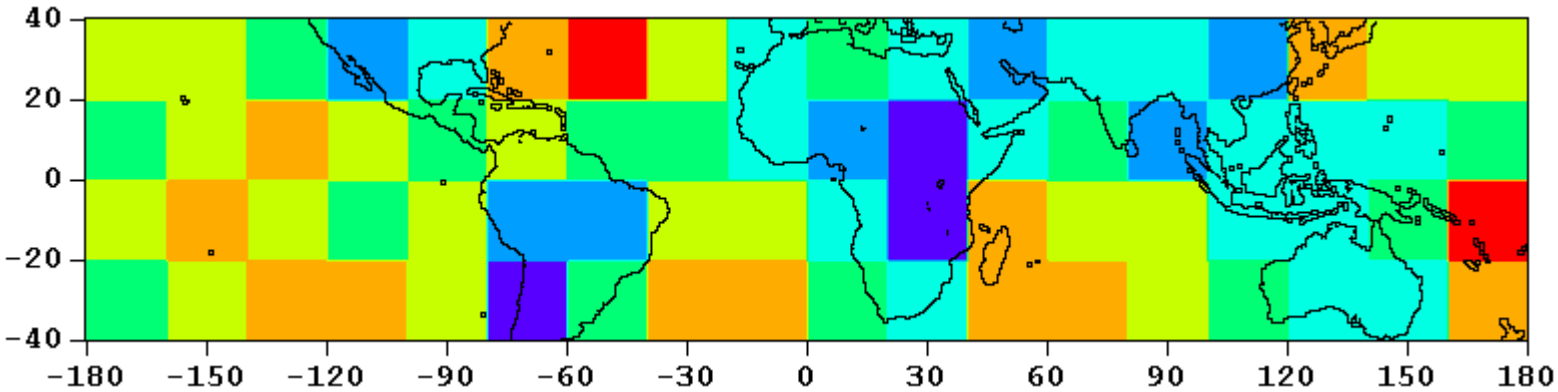




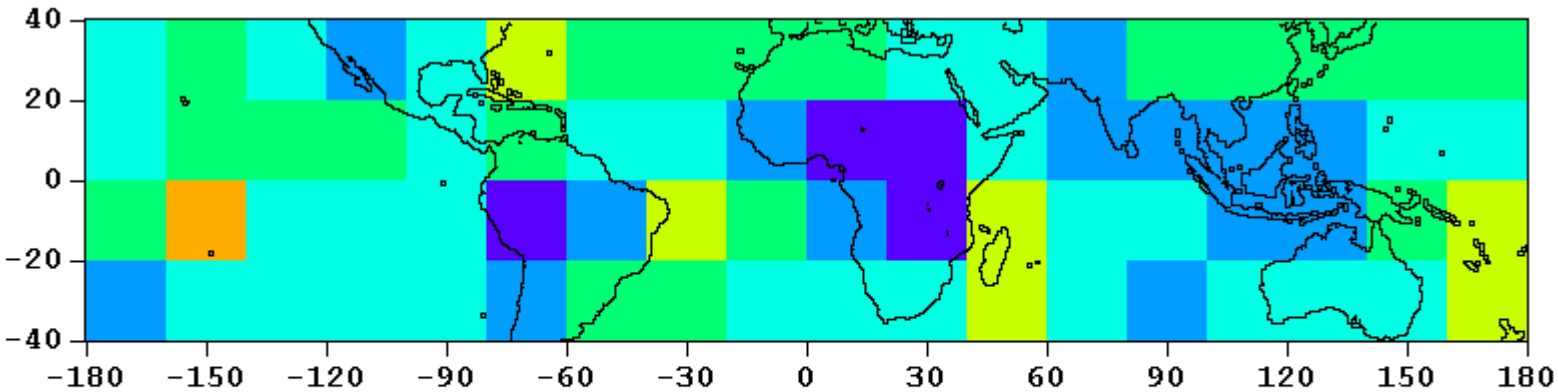
Flux Difference (W m^{-2})

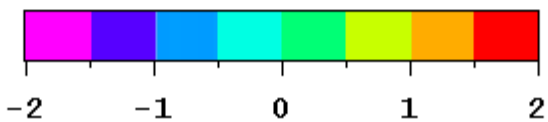
ADM Mean Regional Flux Biases ($\theta < 70°$)

ERBE-Like – DI Flux Difference



SSF Ed2 – DI Flux Difference



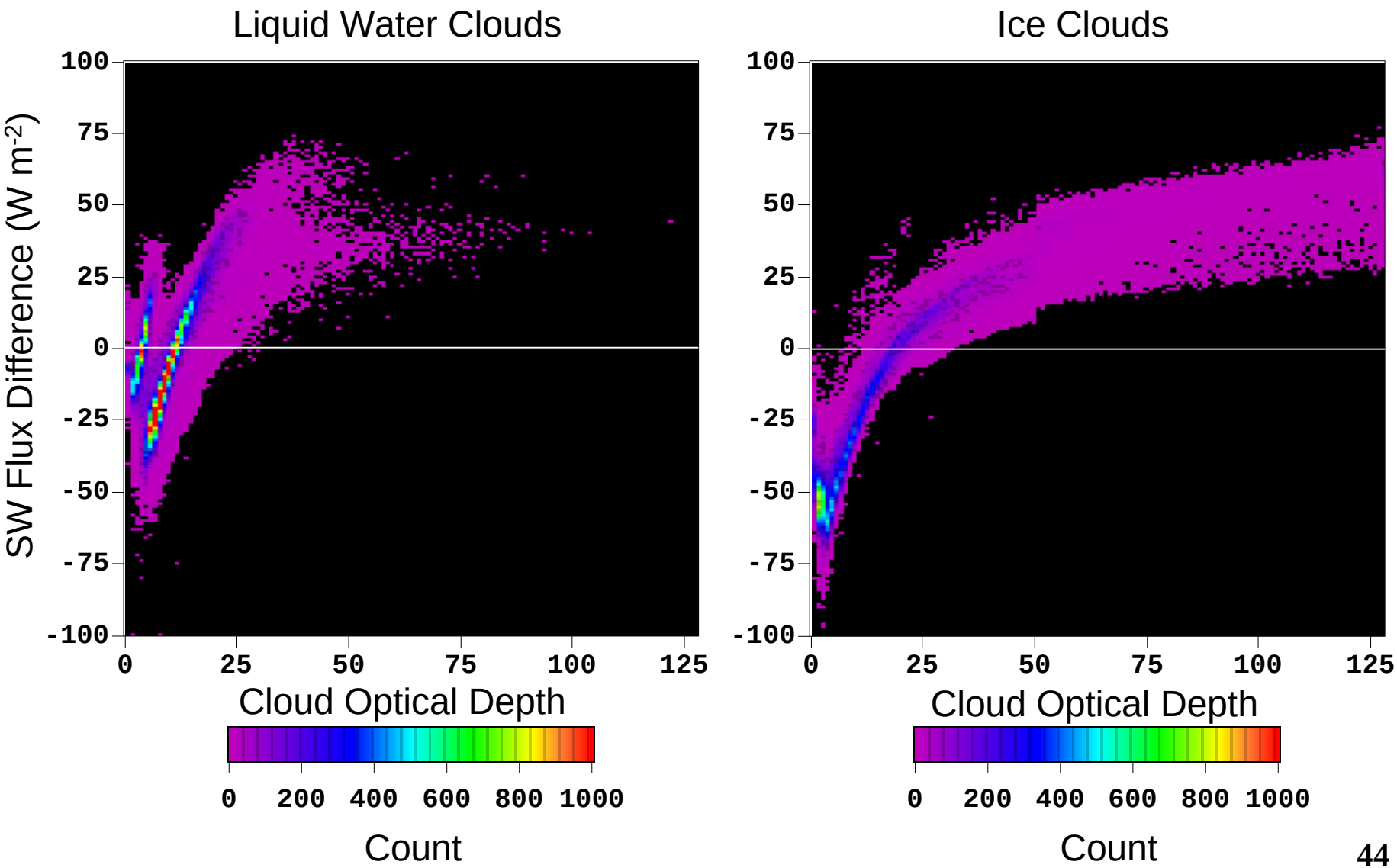


Flux Difference (W m^{-2})

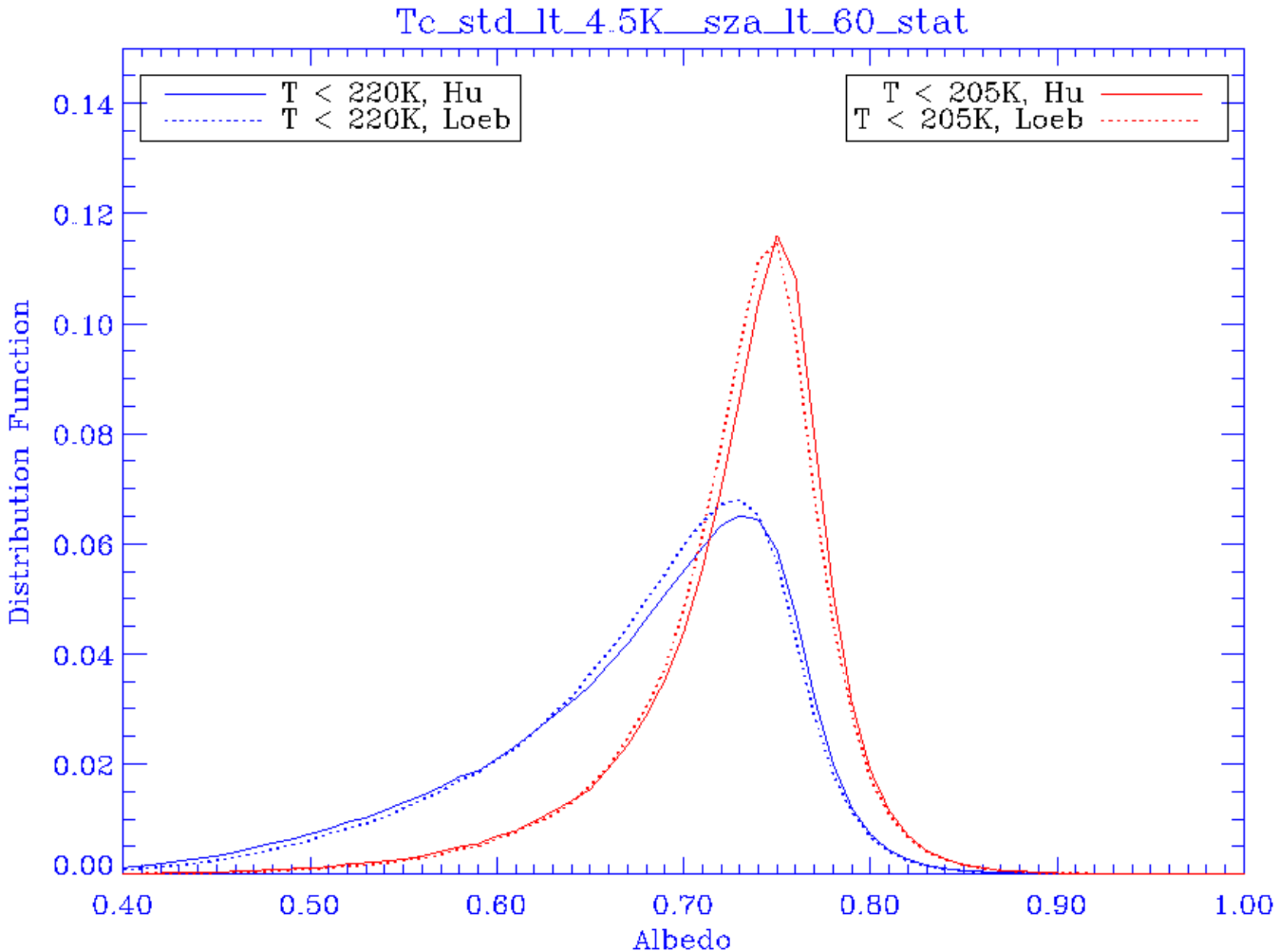
ADM Mean Flux Biases over 20°×20° Regions
(March 1998 Solar Zenith Angle Sampling)
(W m^{-2})

	ERBE-Like		SSF Edition 2	
θ-Range	Δ	σ_Δ	Δ	σ_Δ
$\theta < 50°$	-2.8	1.5	-0.07	1.4
$\theta < 70°$	0.35	0.74	-0.15	0.52
CERES GOAL	0	1	0	1

ERBE-Like – SSF Ed2 SW Flux Difference vs Cloud Optical Depth (Ocean Ocean; θ_o=42° - 44°; θ < 25°)



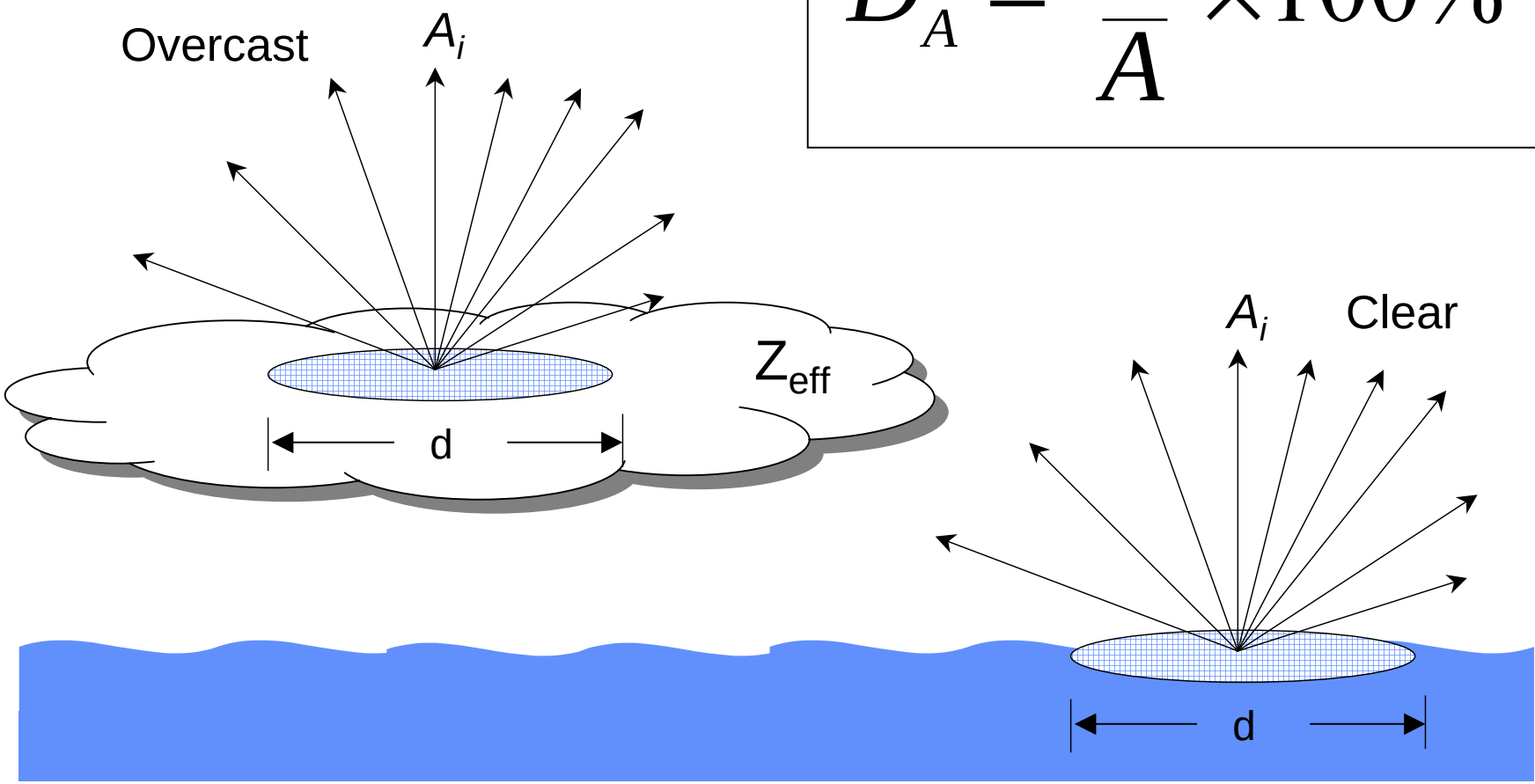
Albedos For Deep Convective Clouds: New ADMs vs Hu



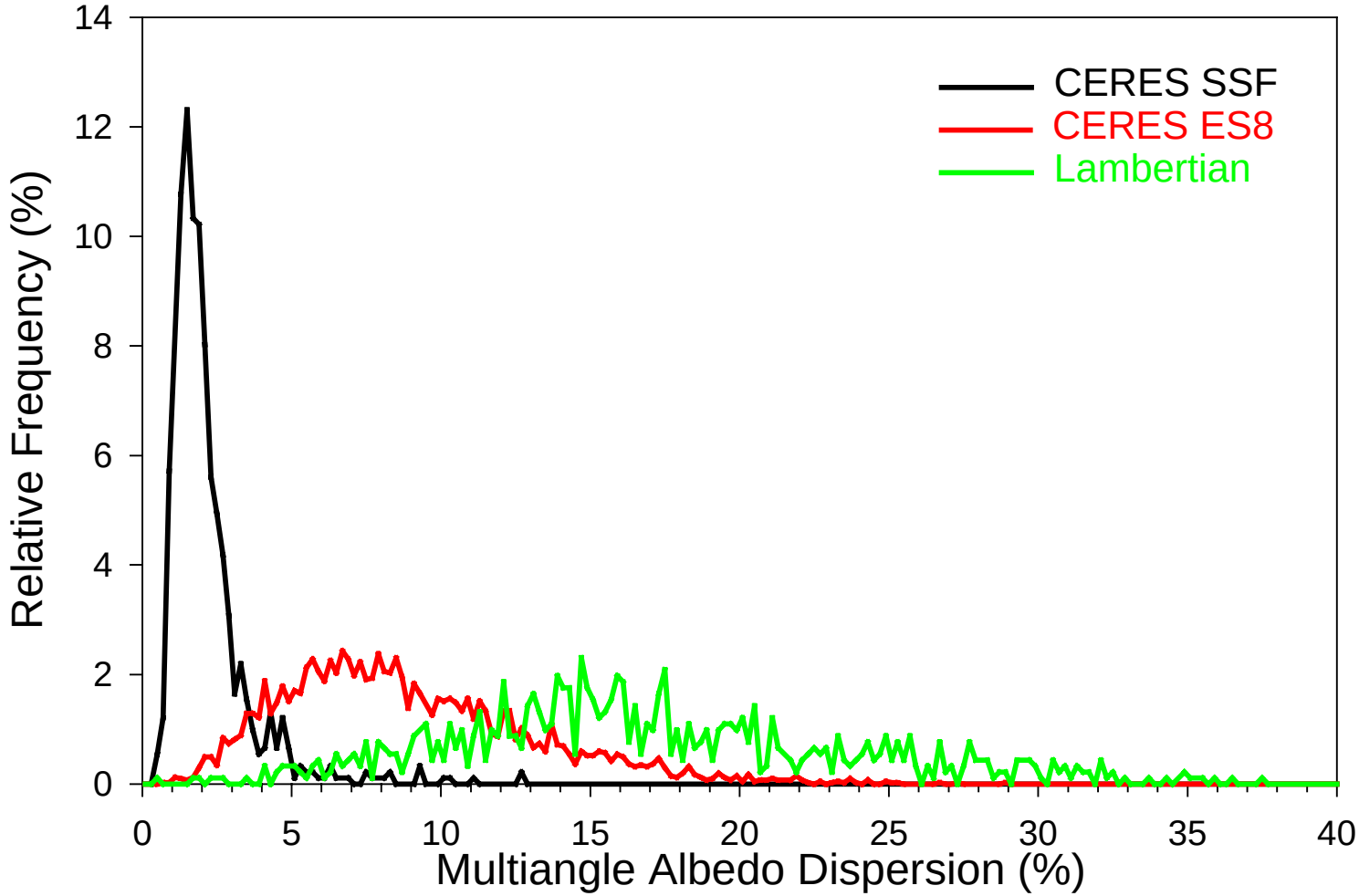
Instantaneous Albedo Errors from CERES Alongtrack Data

Albedo Dispersion Parameter:

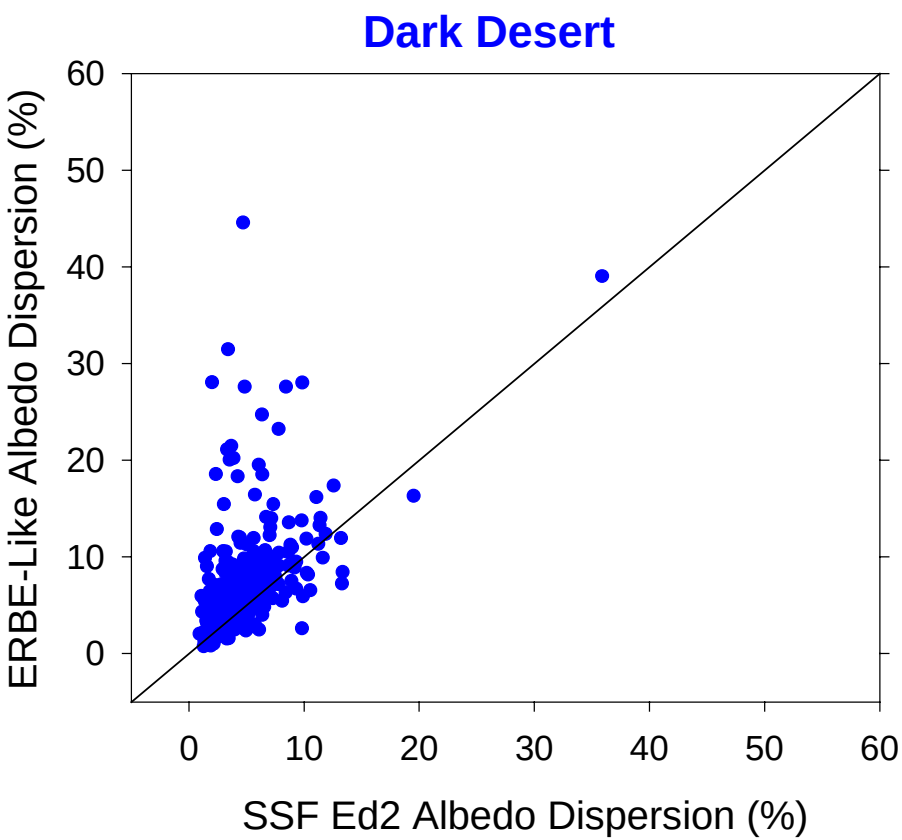
$$D_A = \frac{c_A}{\overline{A}} \times 100\%$$

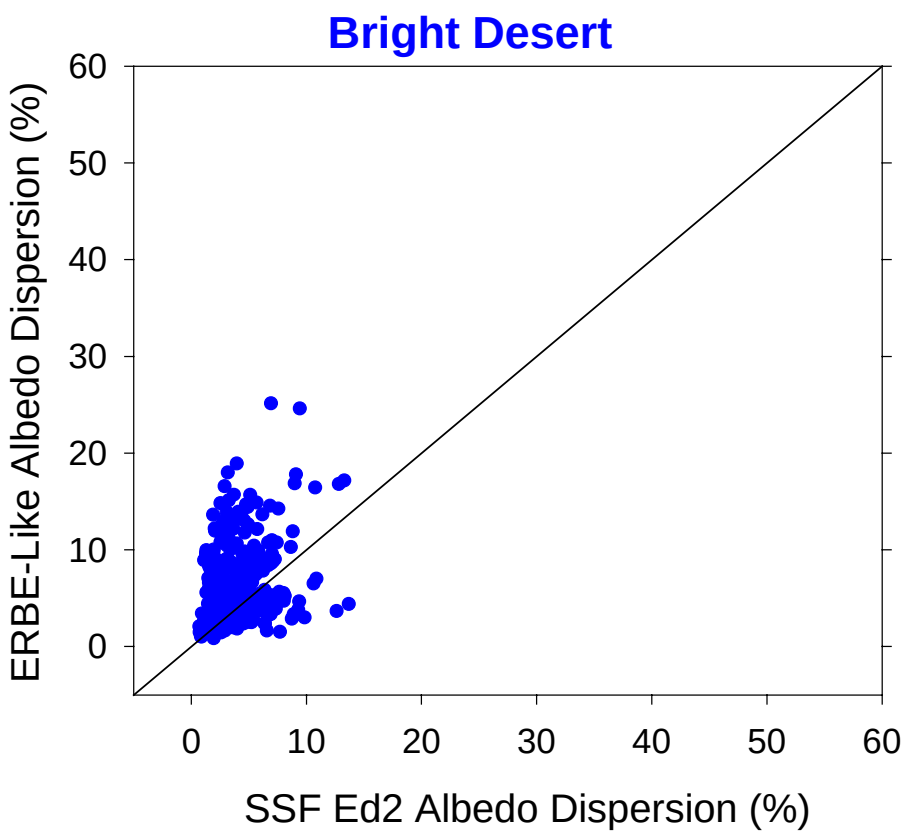


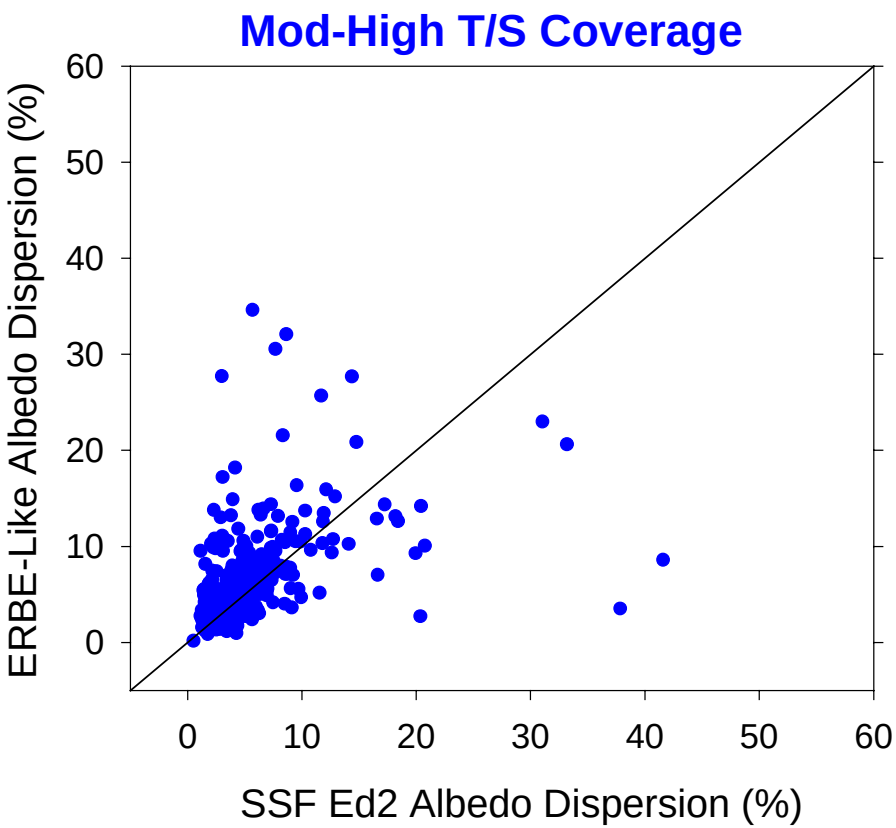
Clear Ocean Alongtrack Albedo Consistency Check

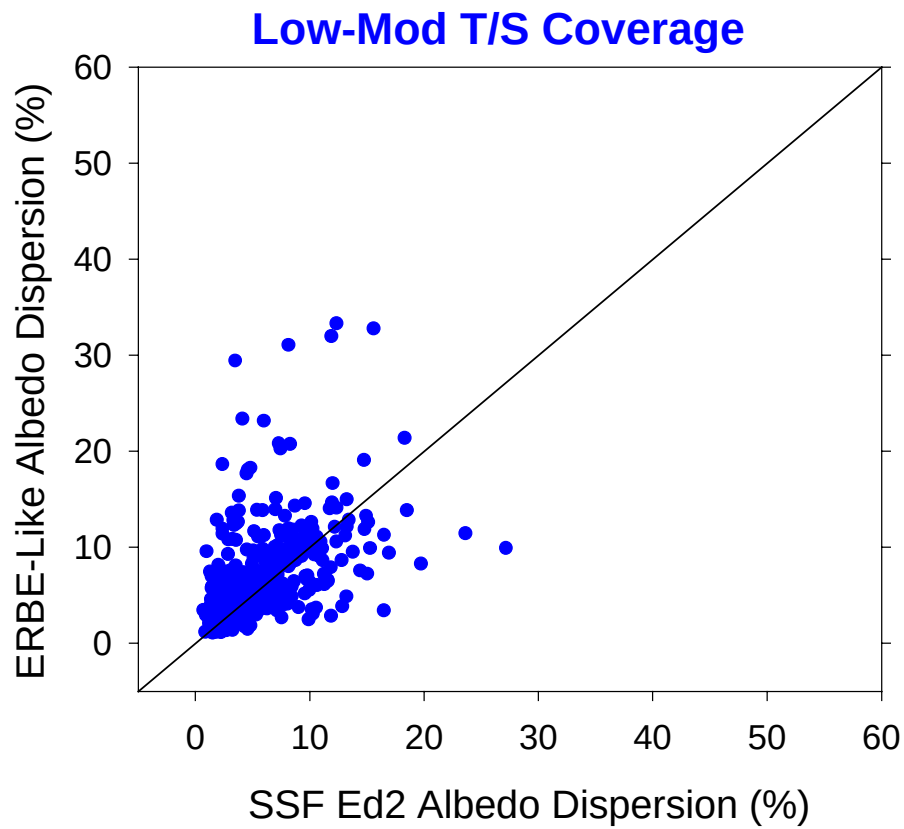


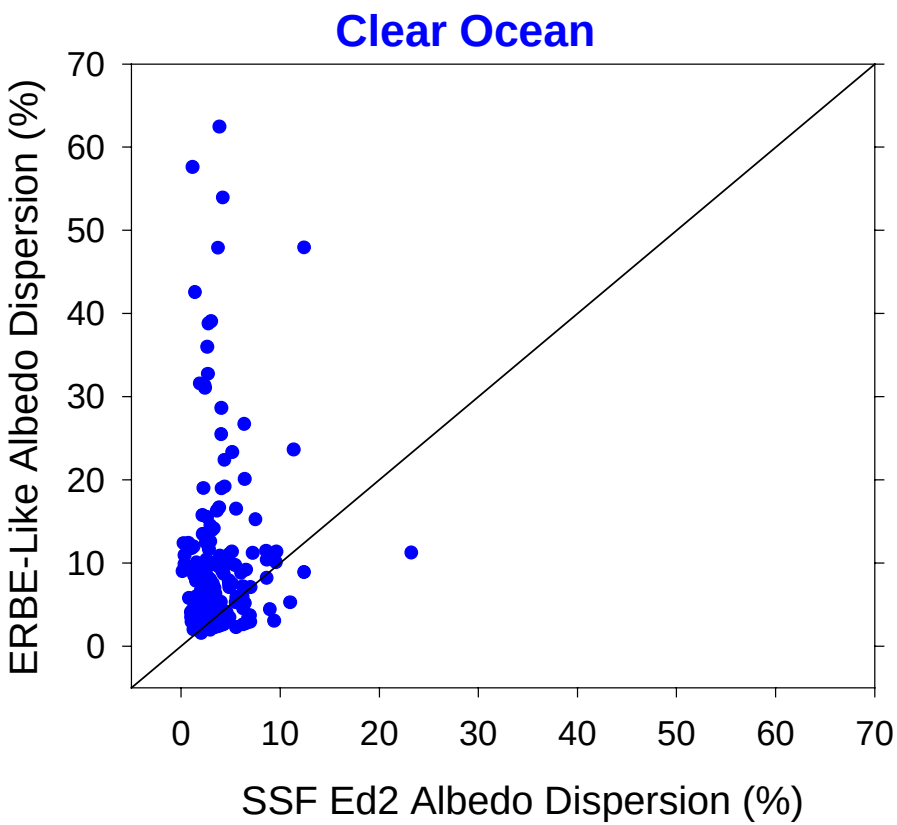
Average Dispersion (%)
CERES SSF= 2.2
CERES ES8= 8.8
Lambertian = 16.9

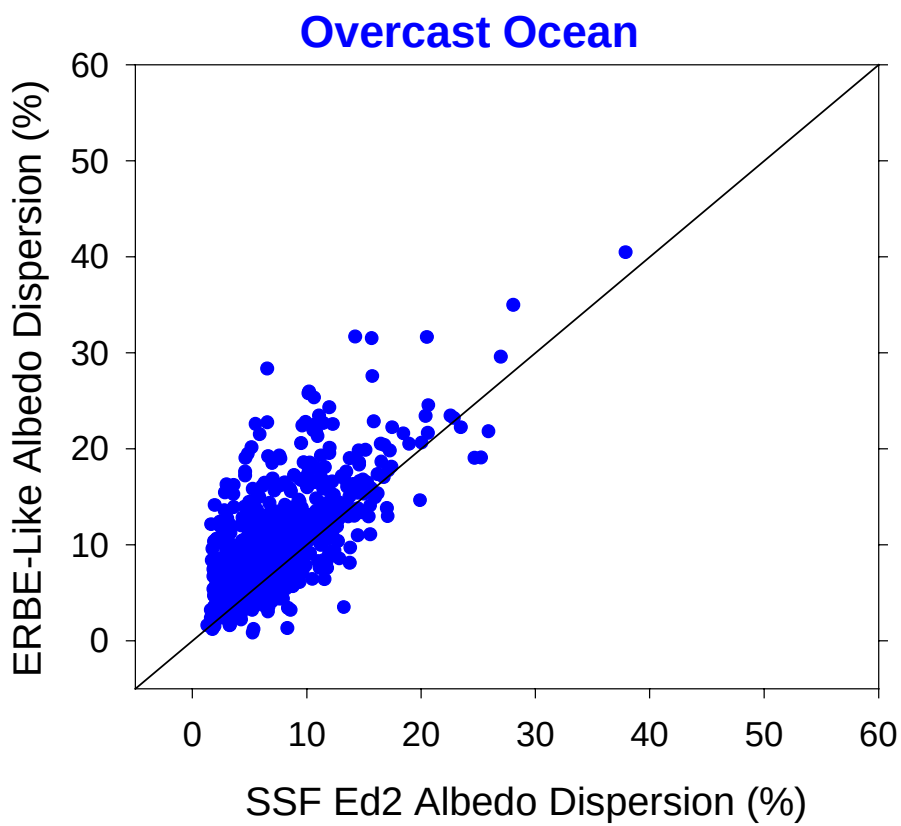

Dark Desert
ERBE-Like Albedo Dispersion (%)
SSF Ed2 Albedo Dispersion (%)
0
10
20
30
40
50
60


Bright Desert
ERBE-Like Albedo Dispersion (%)
SSF Ed2 Albedo Dispersion (%)
0
10
20
30
40
50
60


Mod-High T/S Coverage
ERBE-Like Albedo Dispersion (%)
SSF Ed2 Albedo Dispersion (%)
0
10
20
30
40
50
60

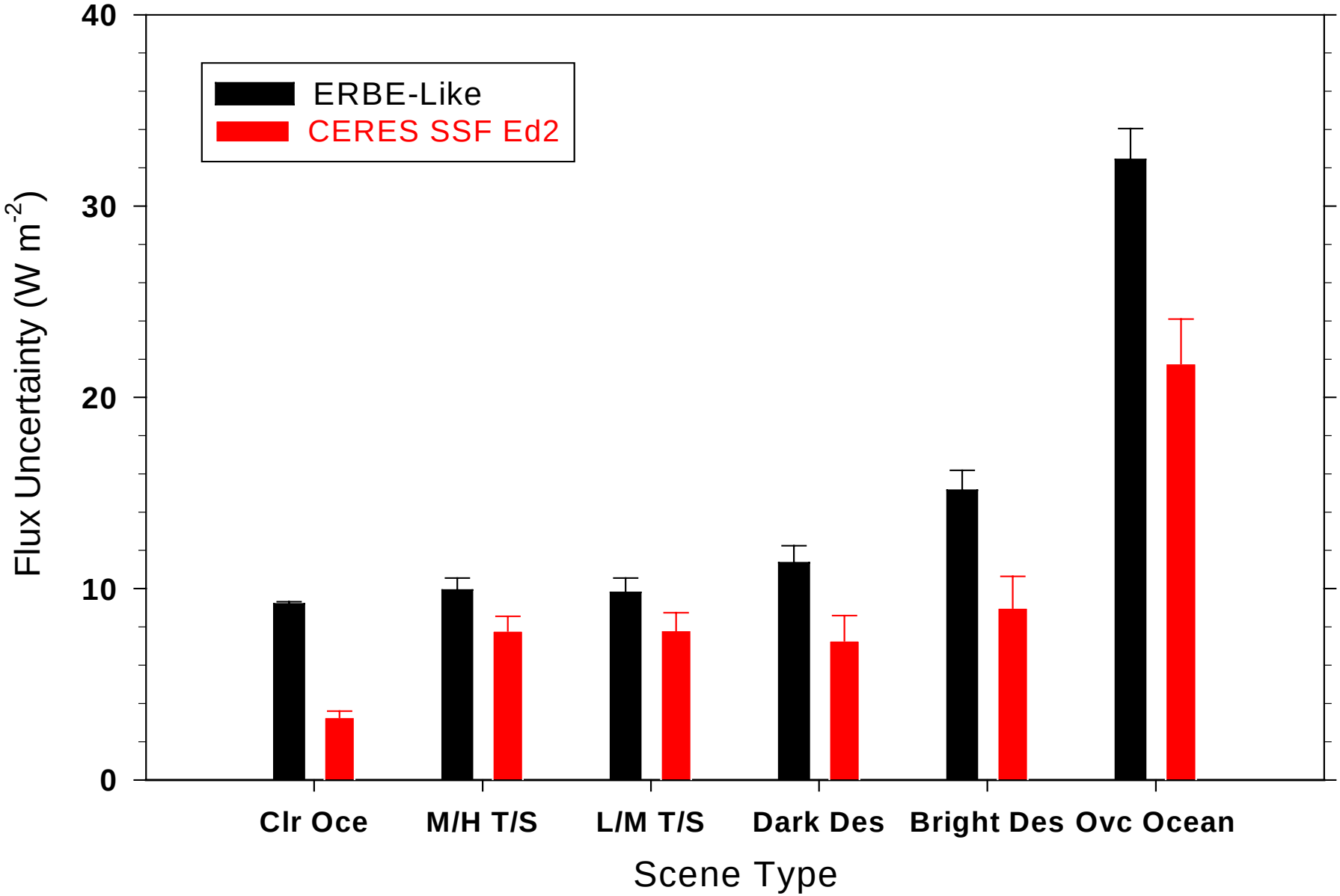

Low-Mod T/S Coverage
ERBE-Like Albedo Dispersion (%)
SSF Ed2 Albedo Dispersion (%)
0
10
20
30
40
50
60


Clear Ocean
ERBE-Like Albedo Dispersion (%)
SSF Ed2 Albedo Dispersion (%)
0
10
20
30
40
50
60
70


Overcast Ocean
ERBE-Like Albedo Dispersion (%)
SSF Ed2 Albedo Dispersion (%)
0
10
20
30
40
50
60

Preliminary Instantaneous TOA SW Flux Uncertainties

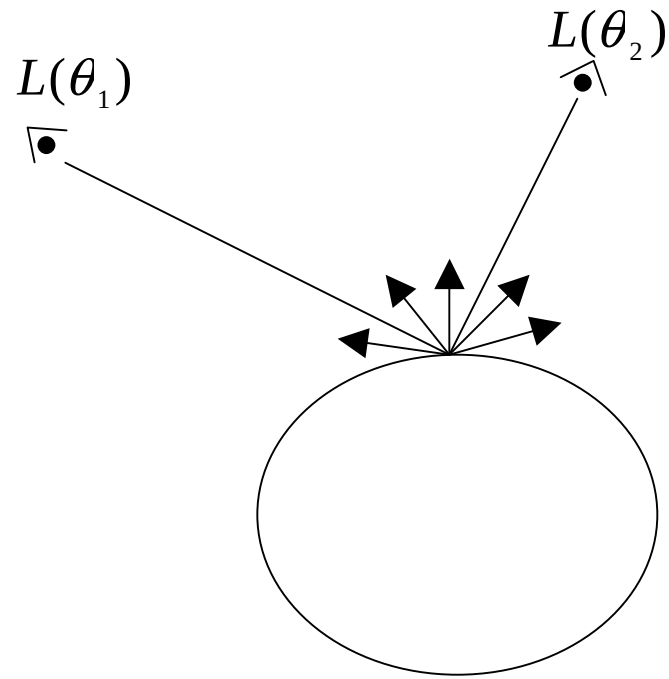
($\mu_o E_o$=1000 W m^{-2})



LW and WN TOA Flux Validation

- Does mean all-sky flux depend on viewing geometry?
- Comparisons with Direct Integration Fluxes:
    - Regional fluxes
    - Latitudinal flux dependence
- Flux consistency as a function of cloud and clear-sky parameters.

TOA LW & WN Flux Estimation from Satellite



Flux:

$$M = 2\pi \int_0^{\pi/2} L(\theta) \cos\theta \sin\theta \, d\theta$$

$L(\theta) =$ Measured Radiance

Instantaneous Flux Estimate:

$$\hat{M} = \frac{\pi L(\theta)}{R(\theta)}$$

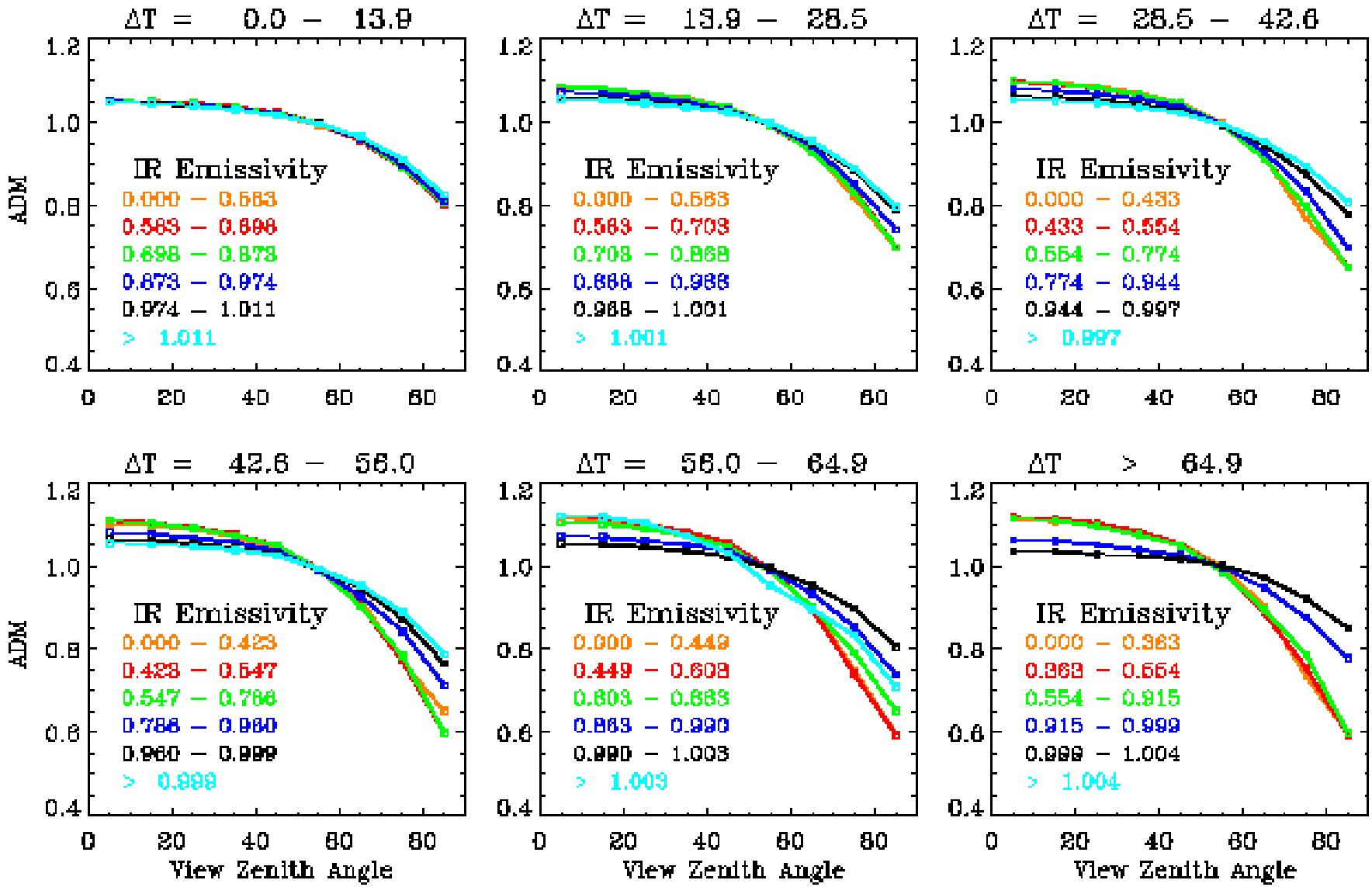
$R(\theta) =$ LW Anisotropic Factor

Scene Types for CERES/TRMM LW and WN ADMs

ADM Category		Parameter Stratification	Total
Clear	Ocean	3 Precipitable Water	12
		4 Vertical Temperature Change	
	Land	3 Precipitable Water	36
		4 Vertical Temperature Change	
		3 Surface Emissivity	
	Desert	3 Precipitable Water	36
		4 Vertical Temperature Change	
		3 Surface Emissivity	
Broken Cloud Field (4 intervals)	Ocean/Land/ Desert	3 Precipitable Water	288 (O) 288 (L) 288 (D)
		6 ΔT (Sfc-Cloud)	
		4 IR Emissivity	
Overcast	Ocean+ Land+Desert	3 Precipitable Water	108
		6 ΔT (Sfc-Cloud)	
		6 IR Emissivity	

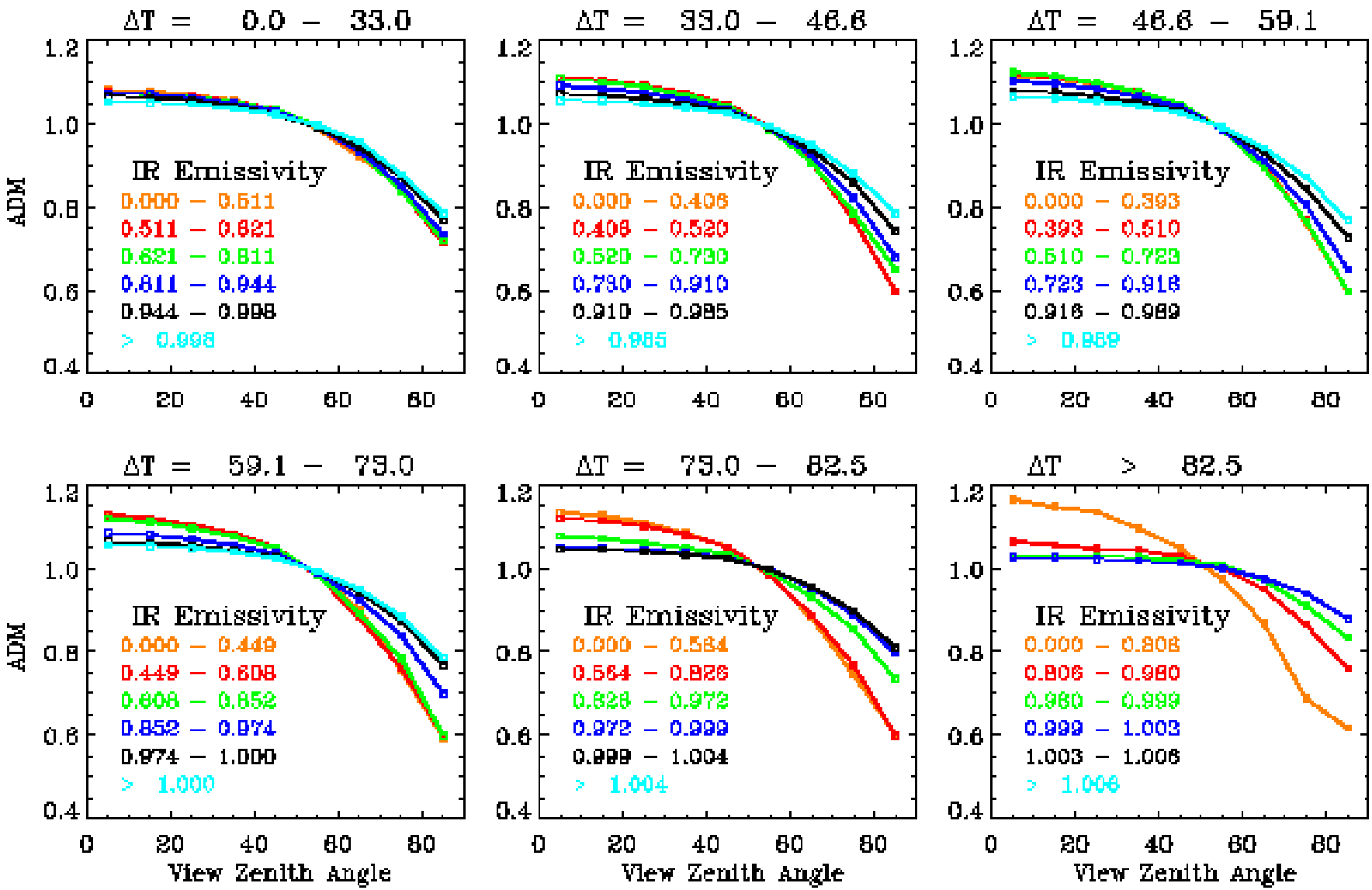
OVERCAST LW ADM

Precipitable Water: 2.57 – 4.63



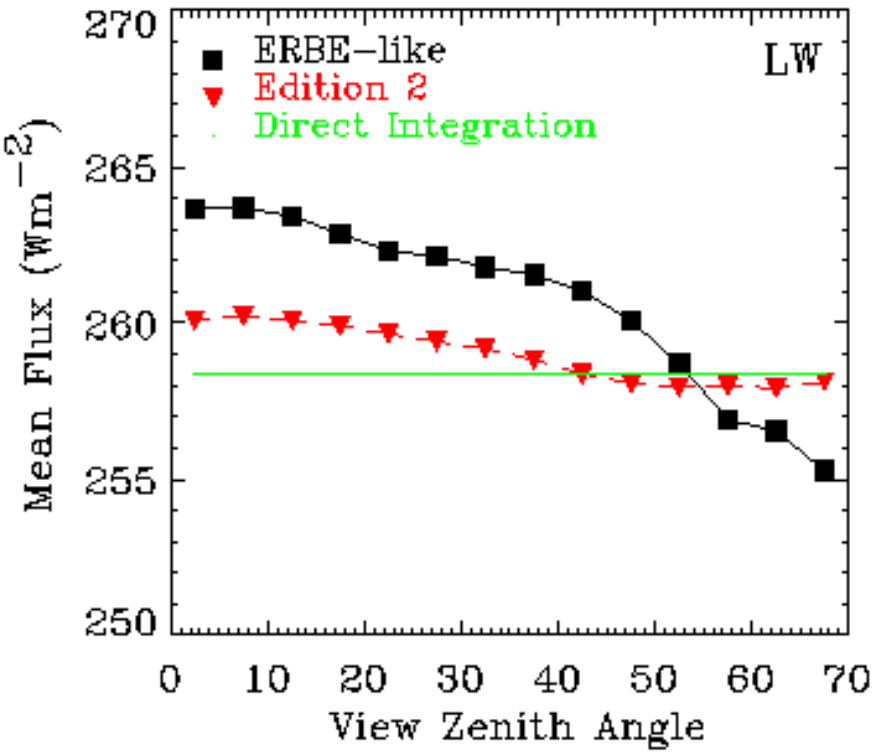
OVERCAST LW ADM

Precipitable Water: 4.63 – 10.00

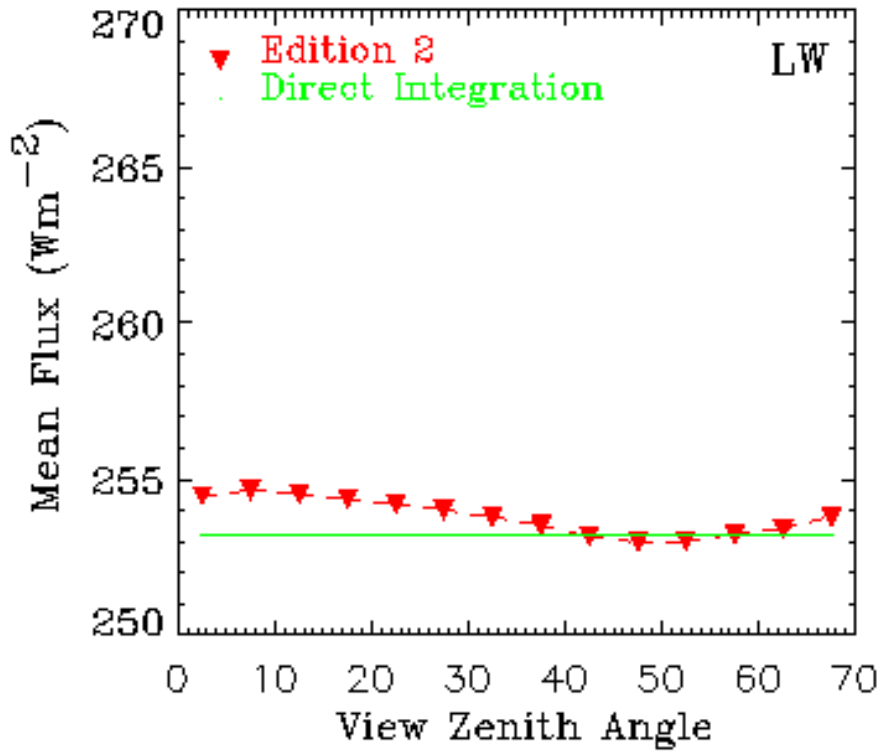


Mean LW Flux vs Viewing Zenith Angle (Jan-Mar 1998)

Daytime

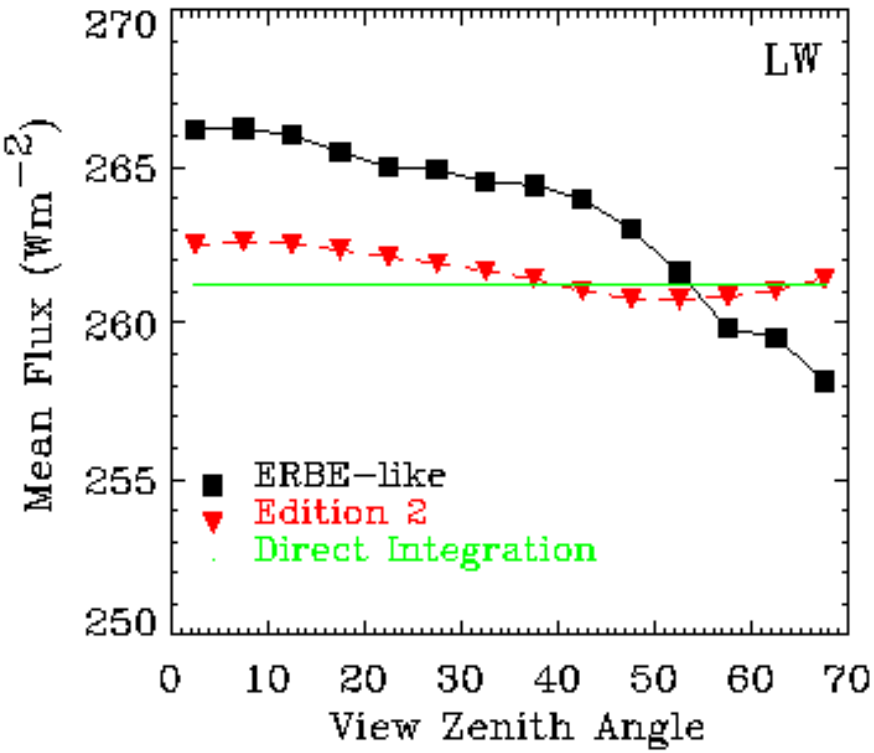


Nighttime

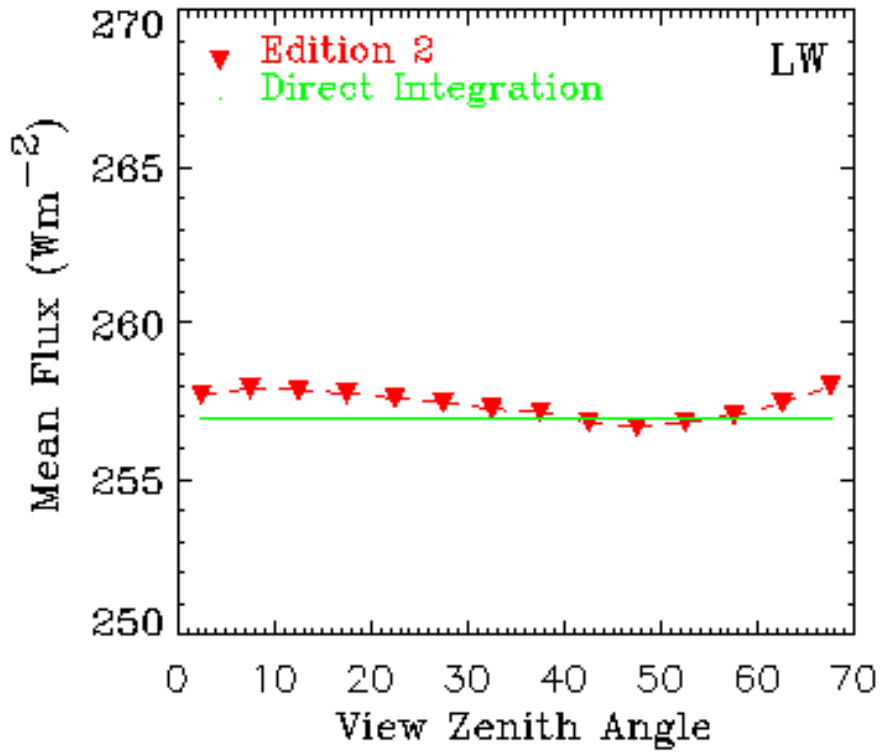


Mean LW Flux vs Viewing Zenith Angle (Jun-Aug 1998)

Daytime



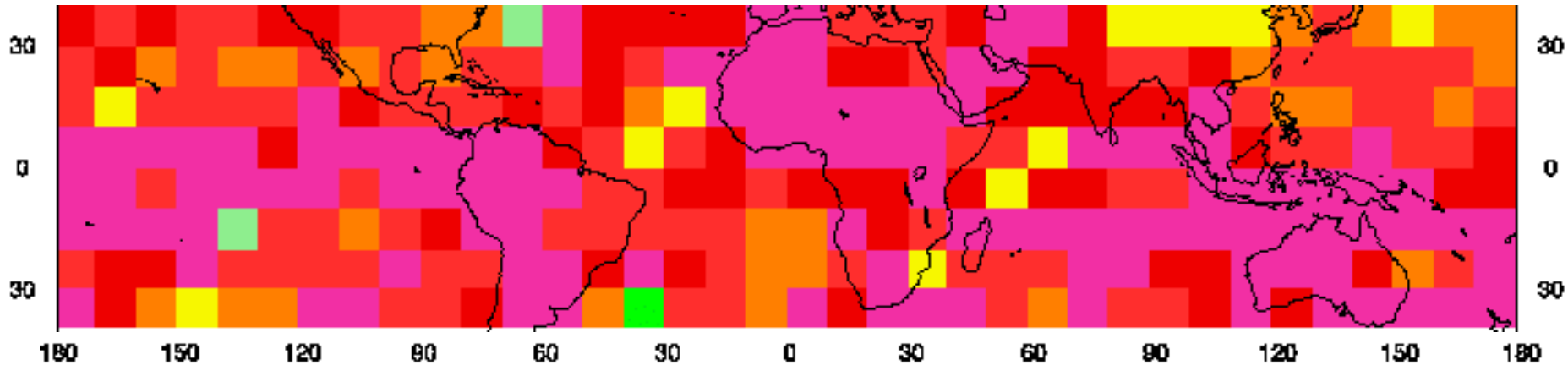
Nighttime



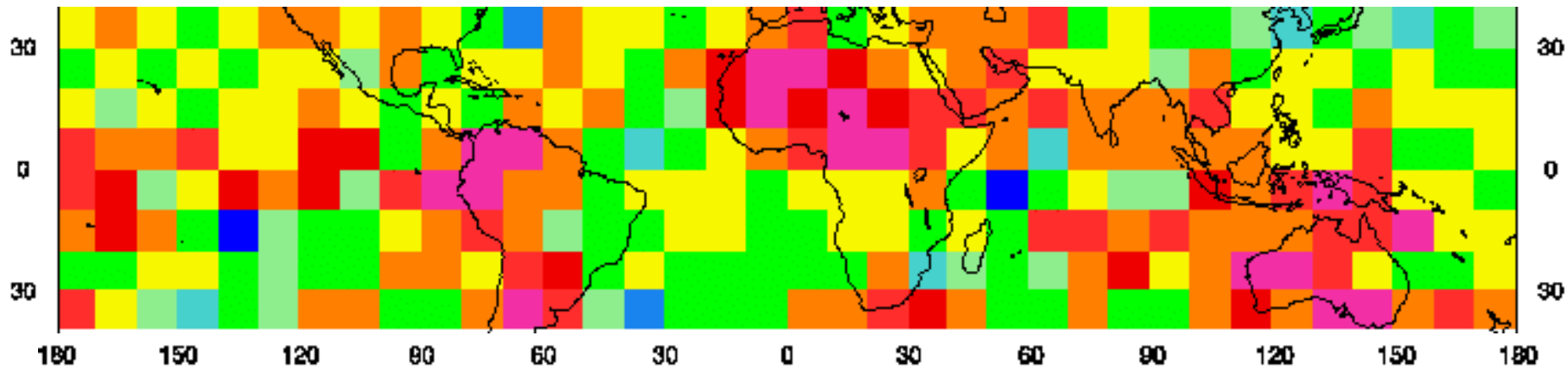
Daytime LW ADM Mean Regional Flux Biases ($\theta < 50°$)

(Jan, Feb, Mar 1998)

ERBE-Like – DI Flux Difference



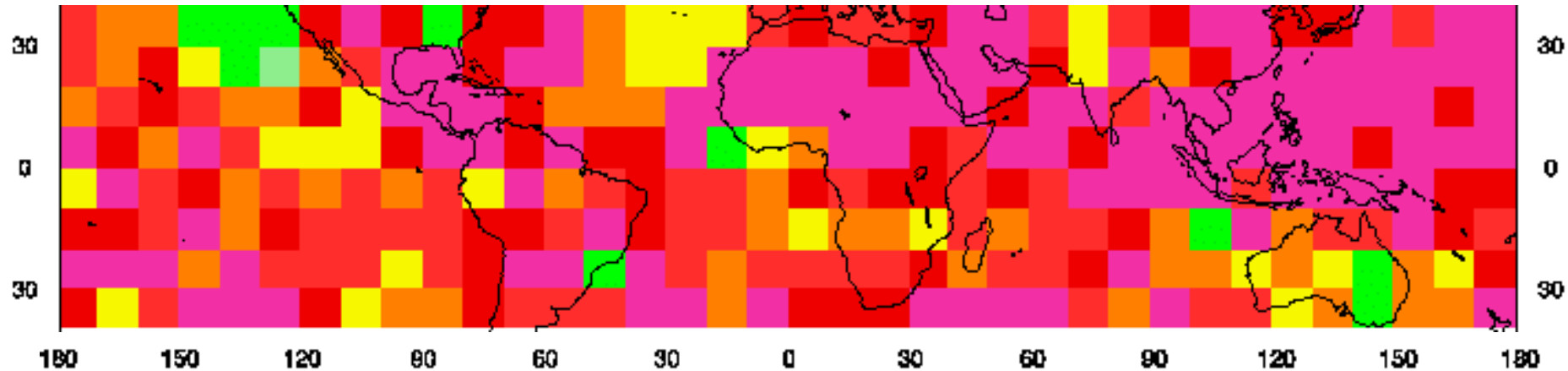
SSF Ed2 – DI Flux Difference



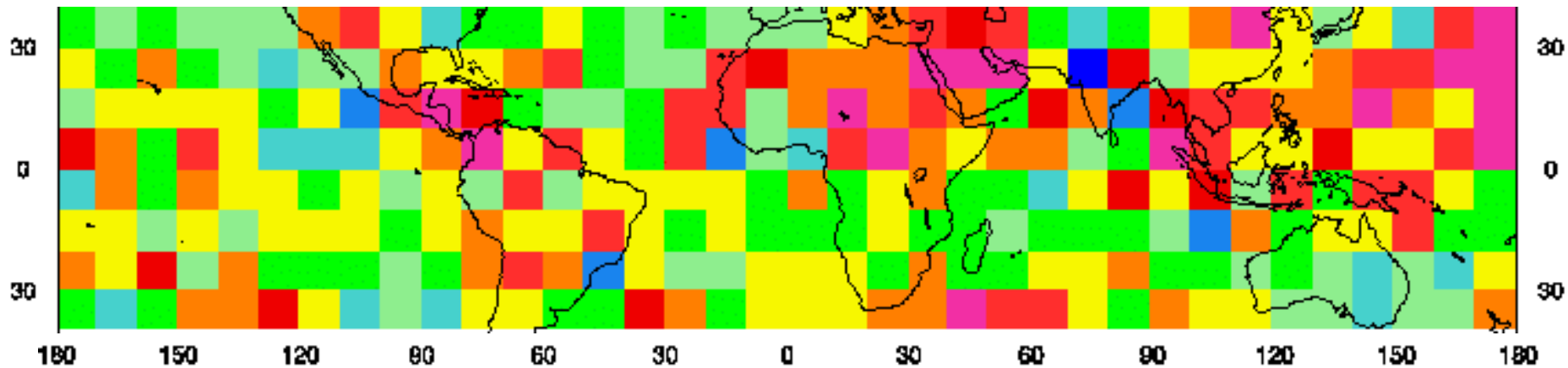
Flux Difference (W m^{-2})

Daytime LW ADM Mean Regional Flux Biases ($\theta < 50°$)
(Jun, Jul, Aug 1998)

ERBE-Like – DI Flux Difference



SSF Ed2 – DI Flux Difference

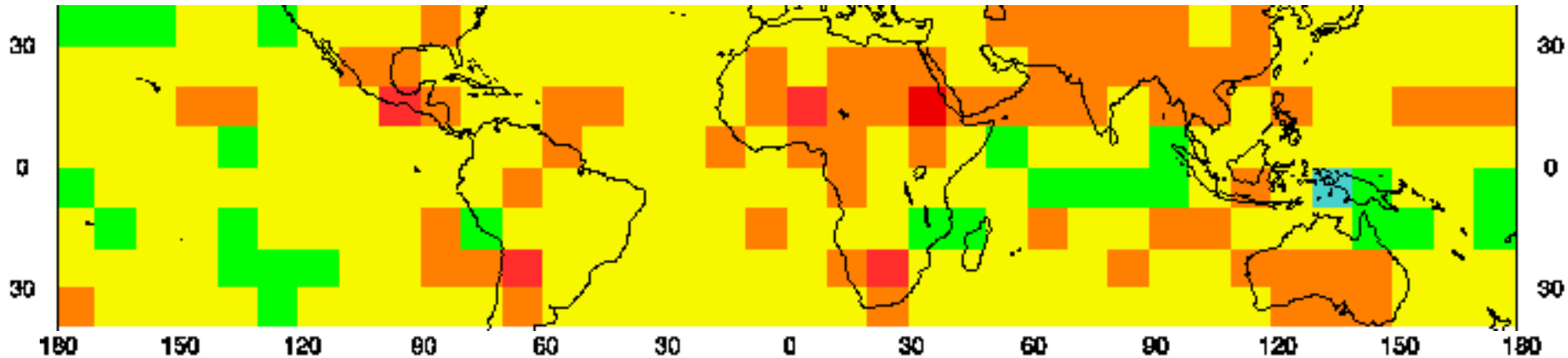


Flux Difference (W m^{-2})

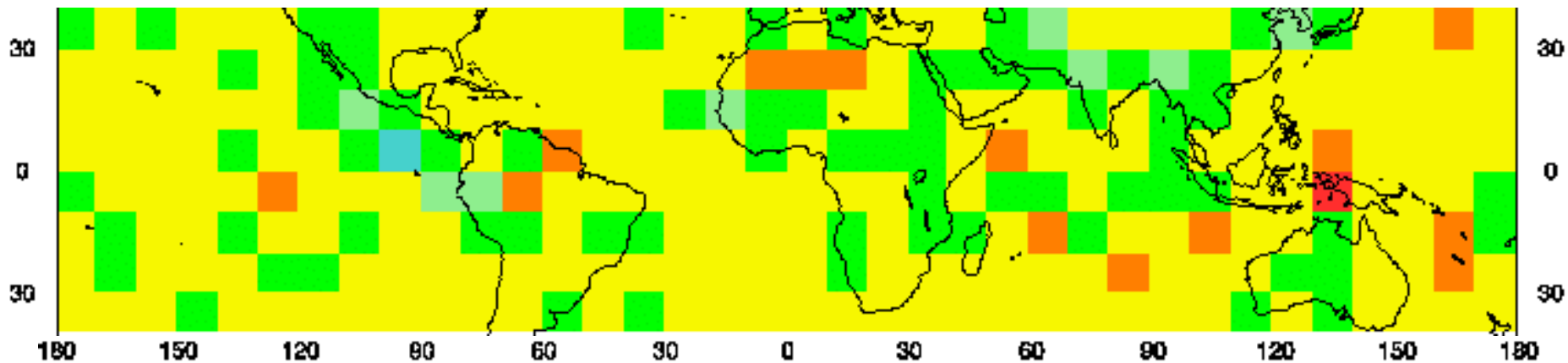
Daytime LW ADM Mean Regional Flux Biases ($\theta < 70°$)

(Jan, Feb, Mar 1998)

ERBE-Like – DI Flux Difference



SSF Ed2 – DI Flux Difference

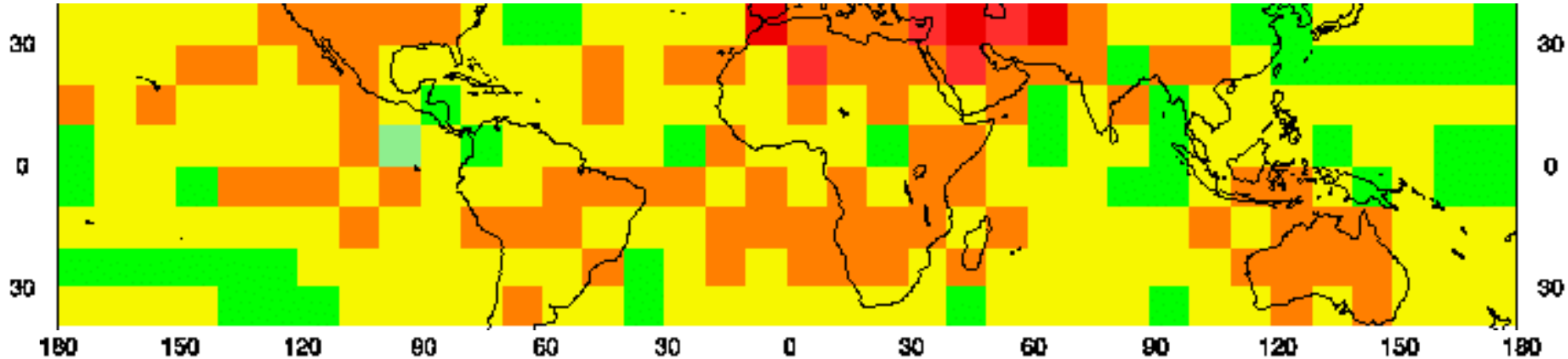


Flux Difference (W m^{-2})

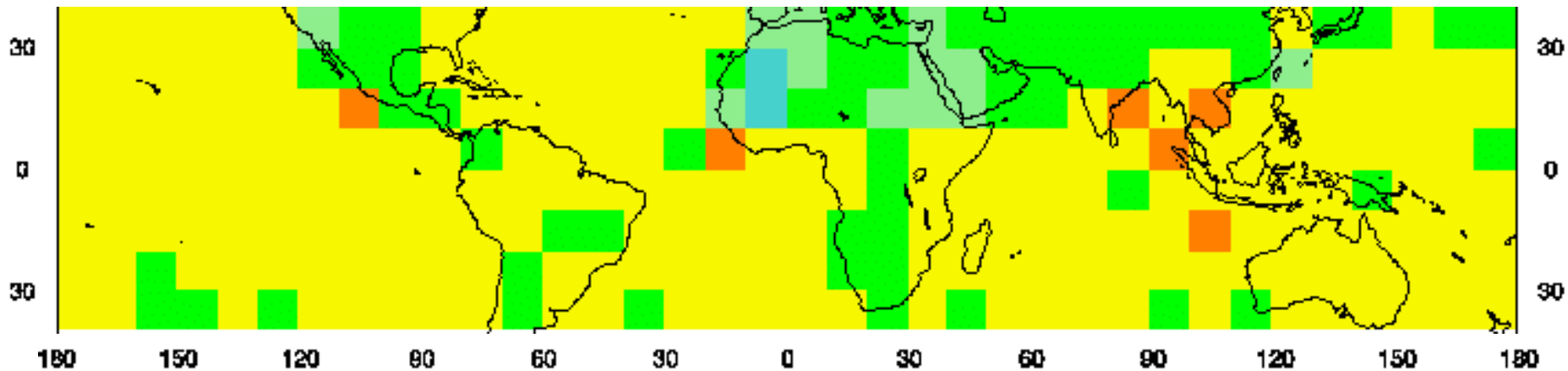
Daytime LW ADM Mean Regional Flux Biases ($\theta < 70°$)

(Jun, Jul, Aug 1998)

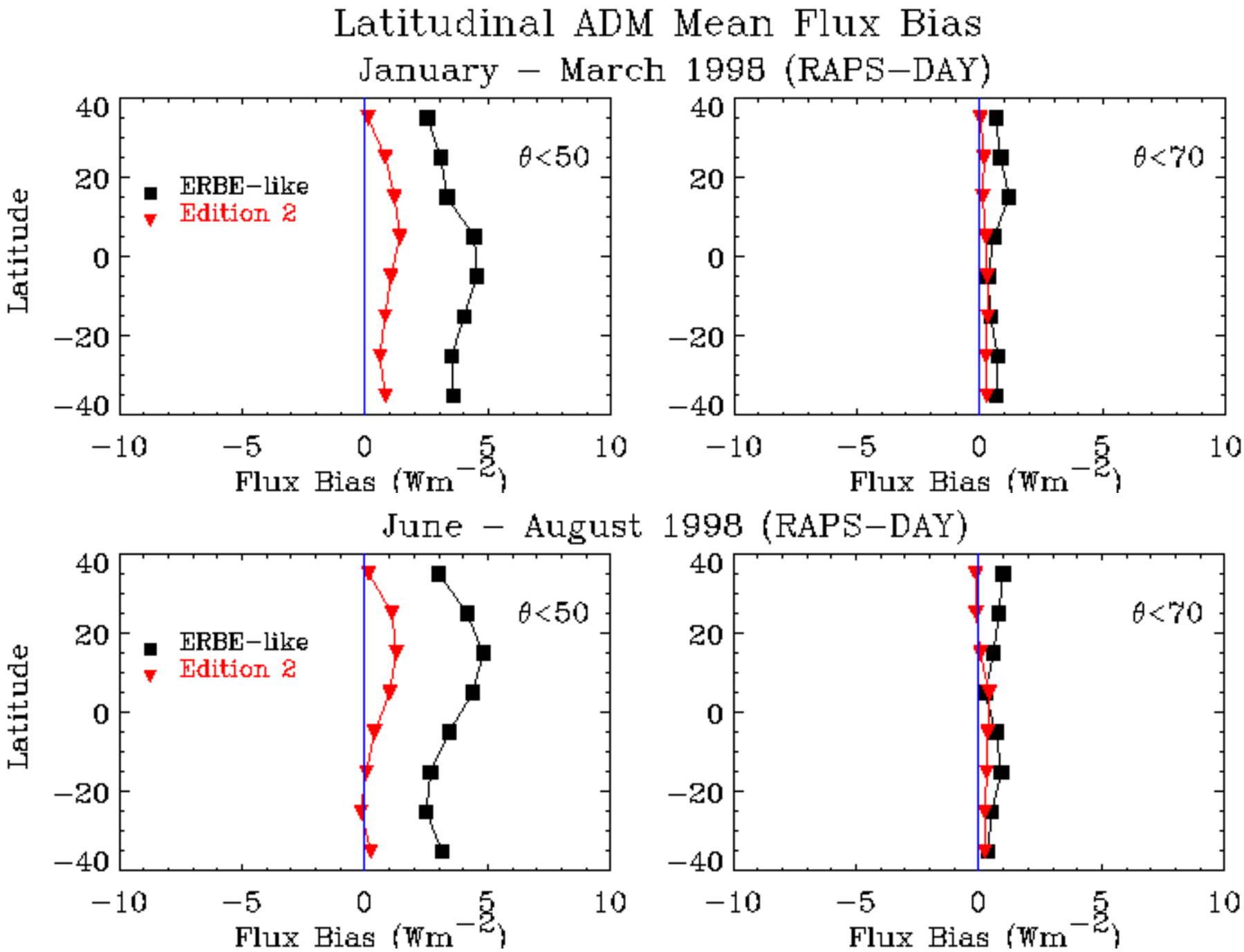
ERBE-Like – DI Flux Difference



SSF Ed2 – DI Flux Difference



Flux Difference (W m^{-2})


Latitudinal ADM Mean Flux Bias
January – March 1998 (RAPS–DAY)
June – August 1998 (RAPS–DAY)
ERBE–like
Edition 2
θ<50
θ<70
Latitude
Flux Bias (Wm^{-2})
40
20
0
−20
−40
−10
−5
0
5
10

ADM Regional LW Flux Biases : Daytime
(10°×10° regions; Jan-March 1998)
(W m^{-2})

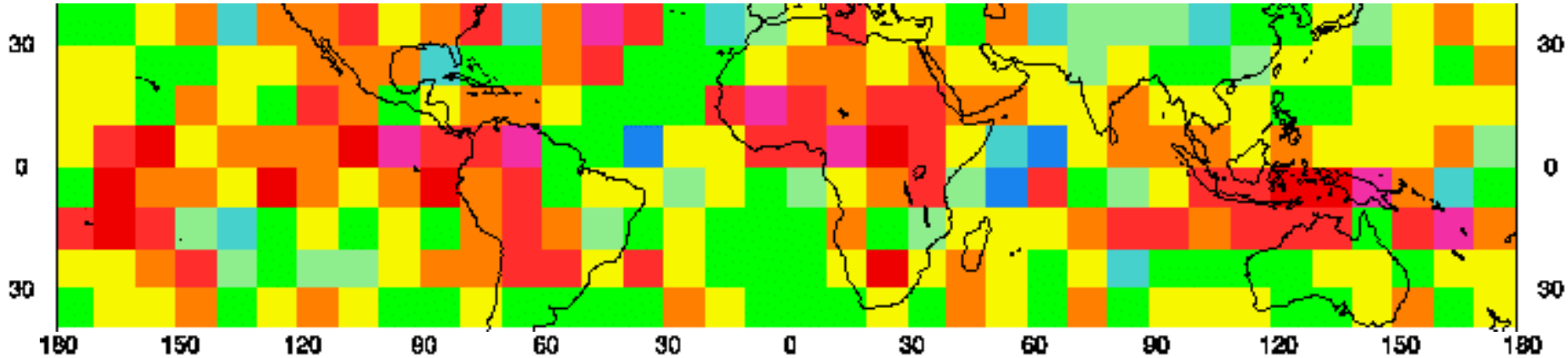
	ERBE-Like		SSF Edition 2	
θ-Range	Δ	σ_Δ	Δ	σ_Δ
$\theta < 50°$	3.7	1.9	0.87	1.7
$\theta < 70°$	0.67	0.60	0.21	0.57
CERES GOAL	0	0.5	0	0.5

ADM Regional LW Flux Biases: Daytime
(10°×10° regions; Jun-Aug 1998)
(W m^{-2})

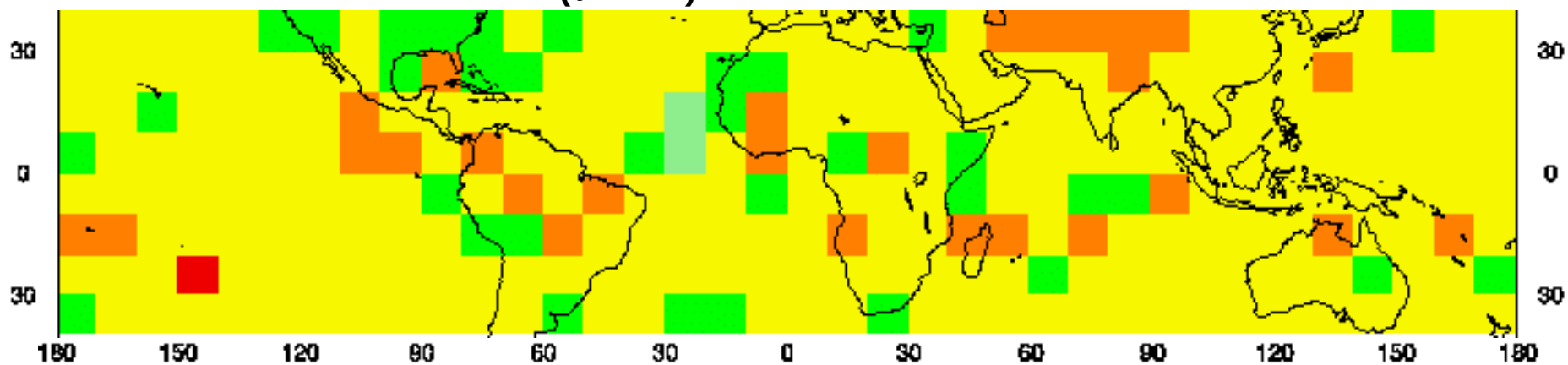
	ERBE-Like		SSF Edition 2	
θ-Range	Δ	σ_Δ	Δ	σ_Δ
$\theta < 50°$	3.5	2.2	0.52	1.9
$\theta < 70°$	0.64	0.68	0.18	0.56
CERES GOAL	0	0.5	0	0.5

Nighttime LW ADM Mean Regional Flux Biases
(Jan, Feb, Mar 1998)

SSF Ed2 – DI Flux Difference (θ < 50°)



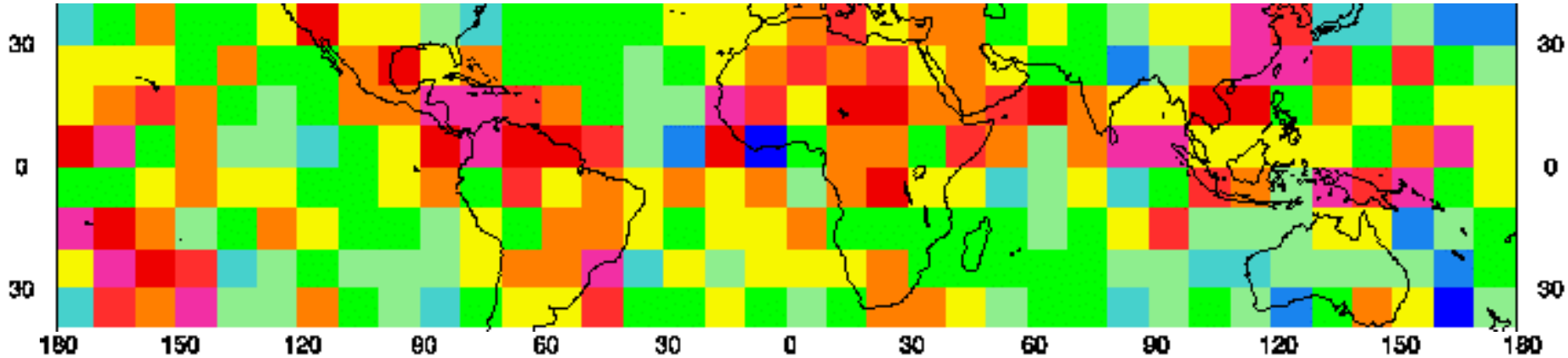
SSF Ed2 – DI Flux Difference (θ < 70°)



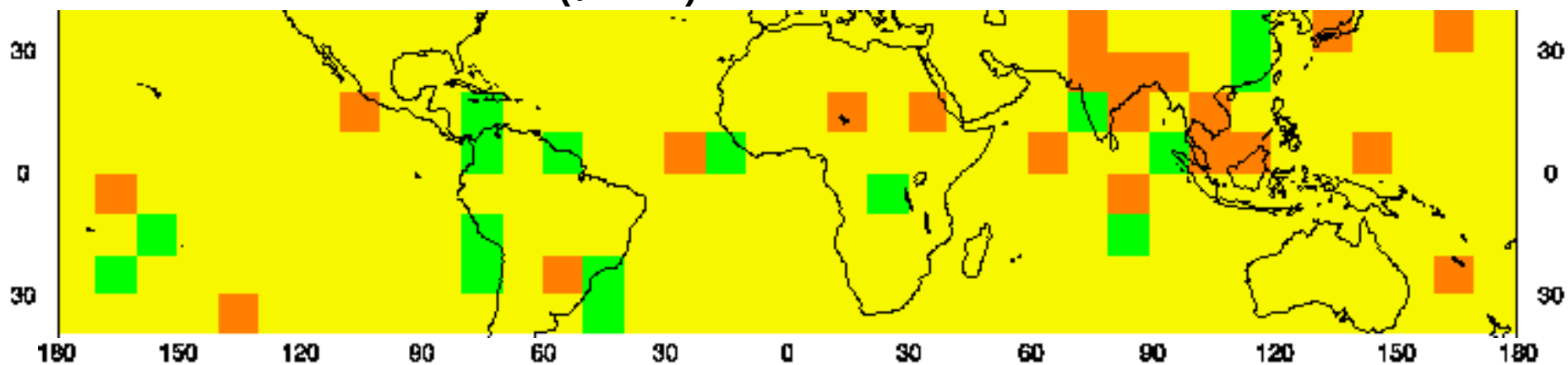
Flux Difference (W m^{-2})

Nighttime LW ADM Mean Regional Flux Biases
(Jun, Jul, Aug 1998)

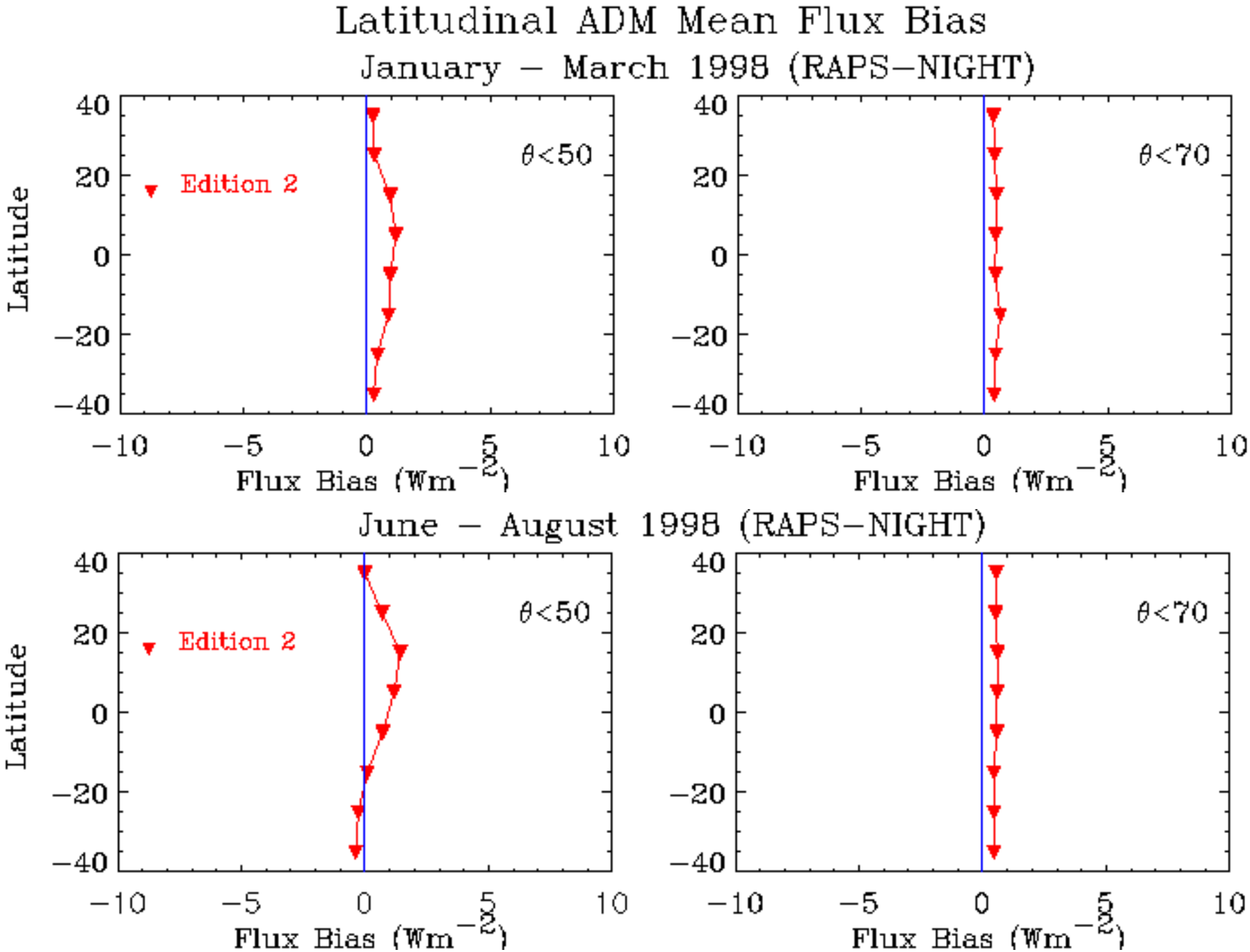
SSF Ed2 – DI Flux Difference (θ < 50°)



SSF Ed2 – DI Flux Difference (θ < 70°)



Flux Difference (W m^{-2})


Latitudinal ADM Mean Flux Bias
January – March 1998 (RAPS–NIGHT)
June – August 1998 (RAPS–NIGHT)
Edition 2
θ<50
θ<70
Latitude
Flux Bias (Wm^{-2})
40
20
0
−20
−40
−10
−5
0
5
10

SSF Edition 2 ADM Regional LW Flux Biases : Nighttime

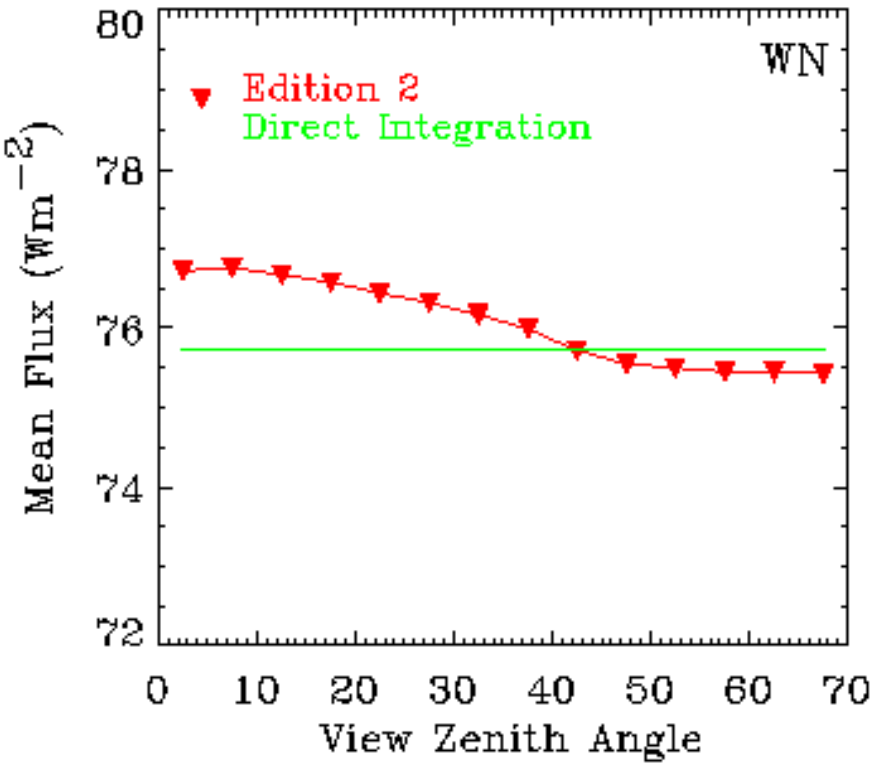
(10°×10° regions)

(W m^{-2})

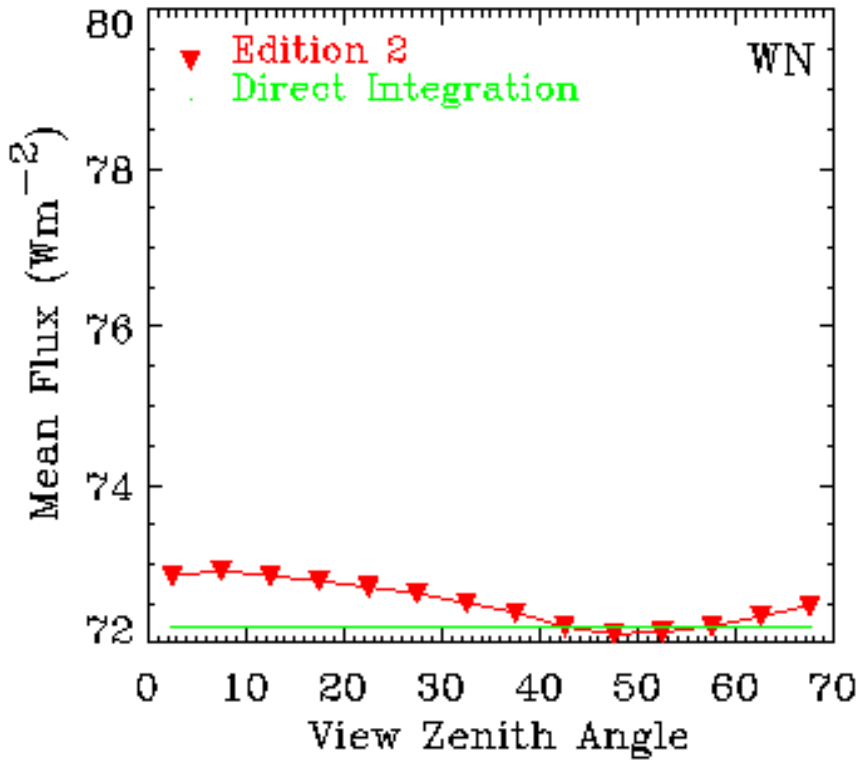
	Jan-Mar		Jun-Aug	
θ-Range	Δ	σ_Δ	Δ	σ_Δ
$\theta < 50°$	0.66	1.5	0.46	2.0
$\theta < 70°$	0.45	0.46	0.52	0.36
CERES GOAL	0	0.5	0	0.5

Mean WN Flux vs Viewing Zenith Angle (Jan-Mar 1998)

Daytime

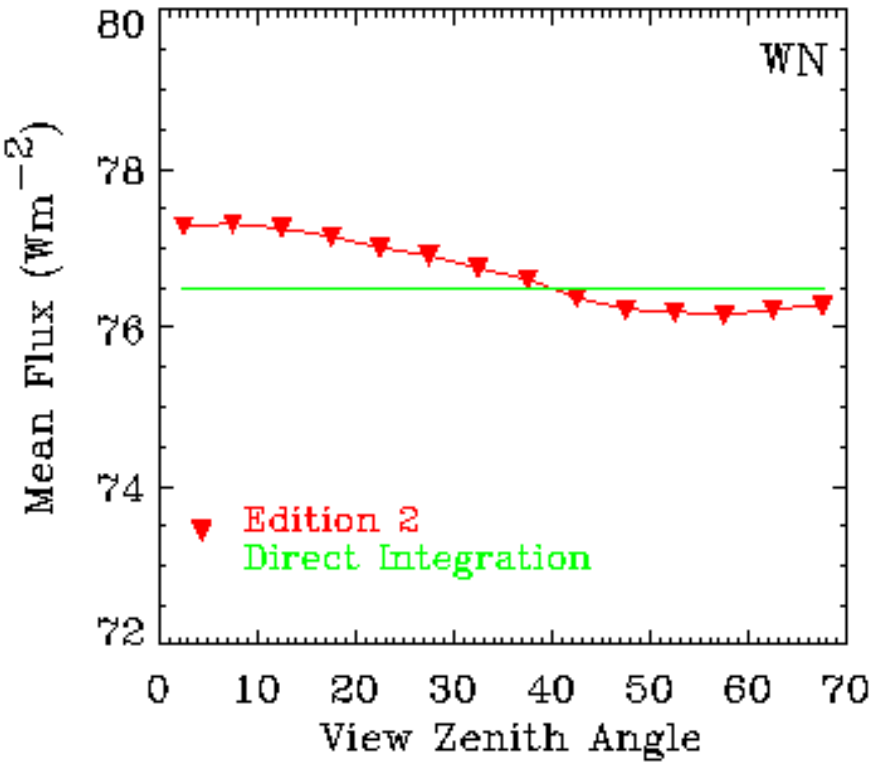


Nighttime

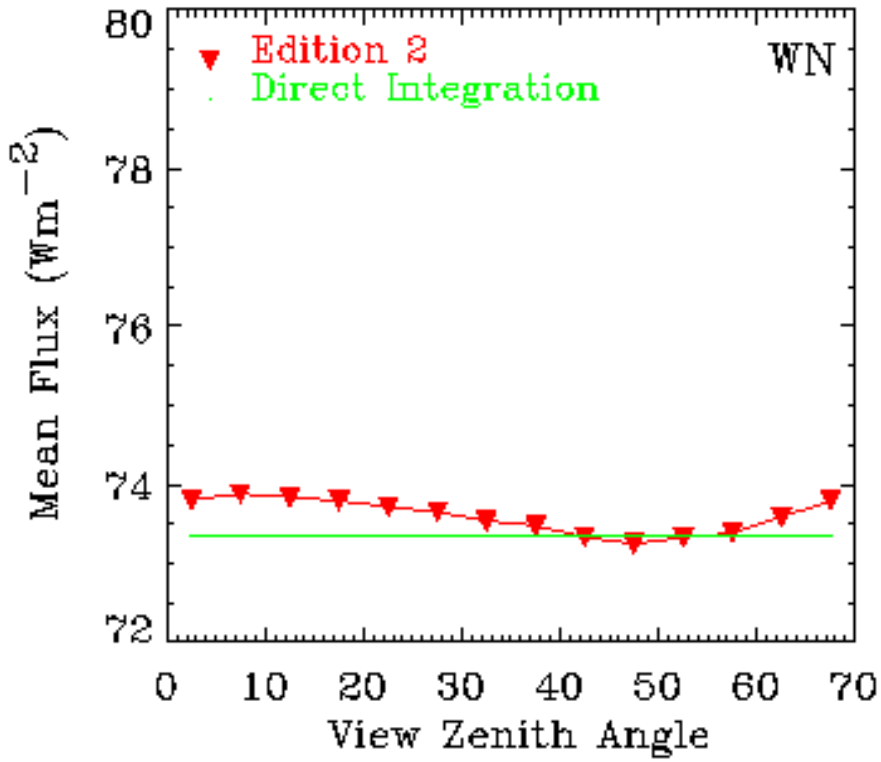


Mean WN Flux vs Viewing Zenith Angle (Jun-Aug 1998)

Daytime

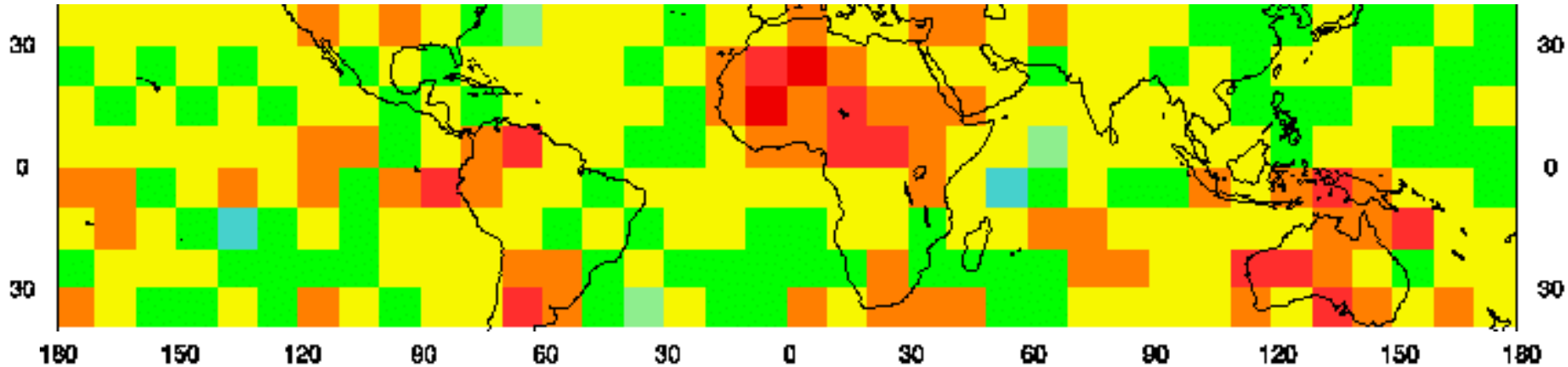


Nighttime

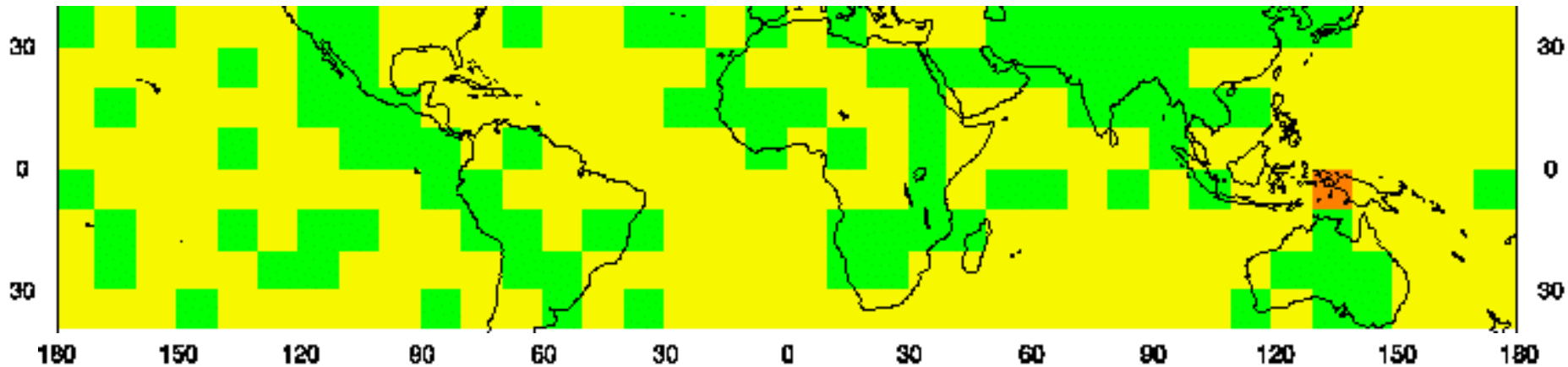


WN ADM Monthly Mean Regional Flux Biases
(Jan, Feb, Mar 1998)

SSF Ed2 – DI Flux Difference ($\theta < 50°$)



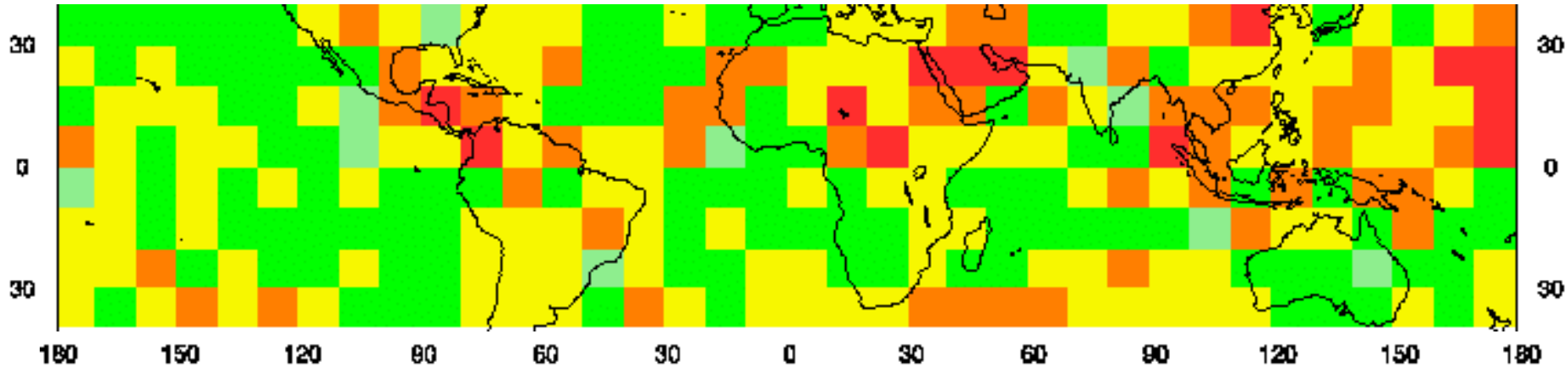
SSF Ed2 – DI Flux Difference ($\theta < 70°$)



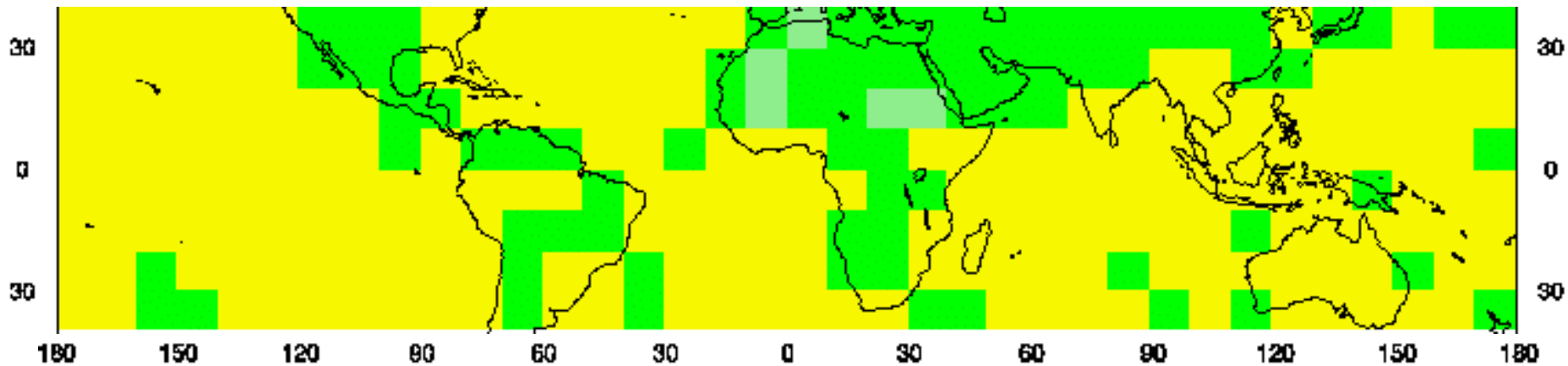
Flux Difference (W m^{-2})

WN ADM Monthly Mean Regional Flux Biases
(Jun, Jul, Aug 1998)

SSF Ed2 – DI Flux Difference (θ < 50°)



SSF Ed2 – DI Flux Difference (θ < 70°)



Flux Difference (W m^{-2})

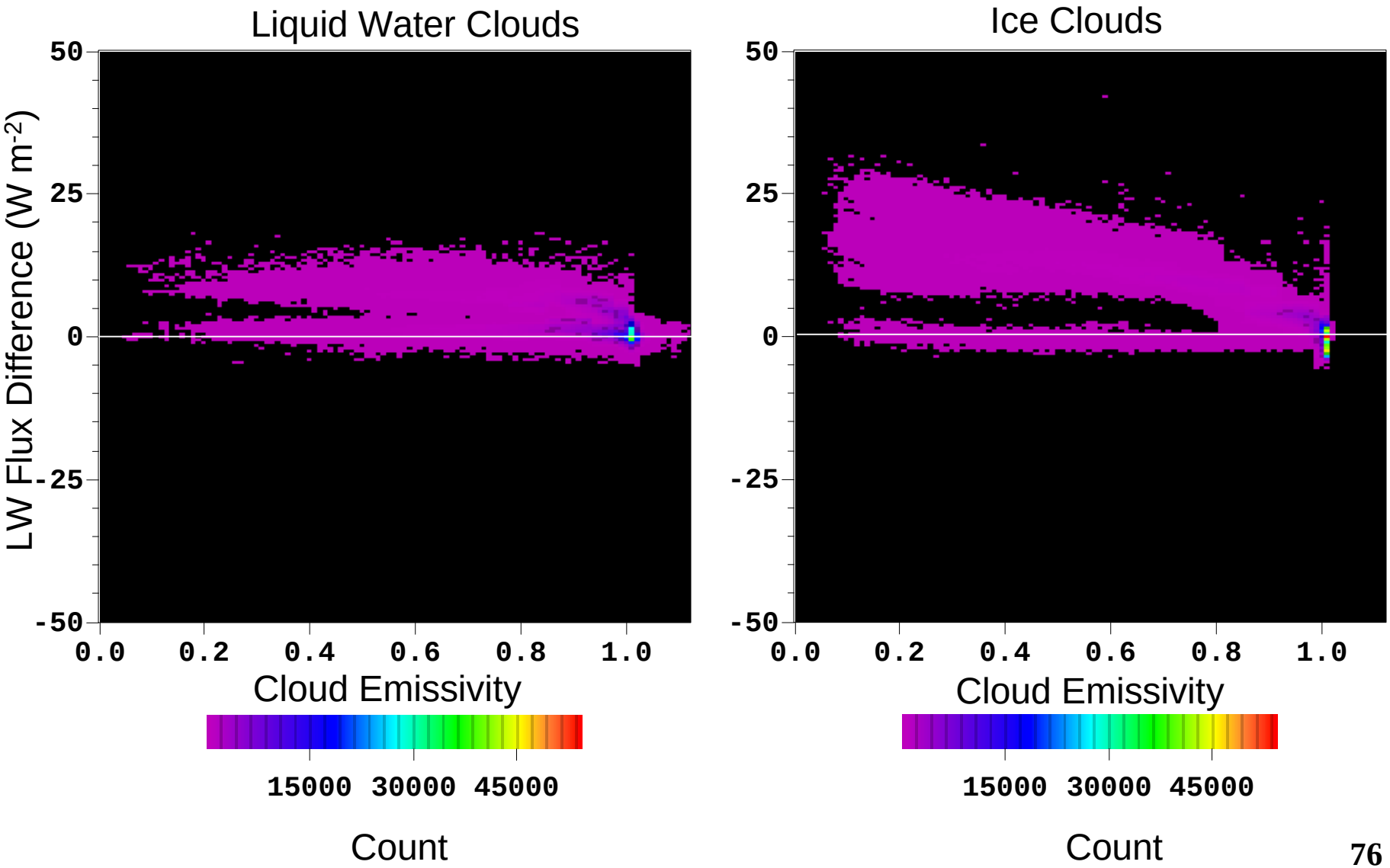
SSF Edition 2 ADM Regional WN Flux Biases: Daytime
(10°×10° regions)
(W m^{-2})

	Jan-Mar		Jun-Aug	
θ-Range	Δ	σ_Δ	Δ	σ_Δ
$\theta < 50°$	0.48	0.79	0.33	0.87
$\theta < 70°$	0.07	0.27	0.03	0.32
CERES GOAL	-	-	-	-

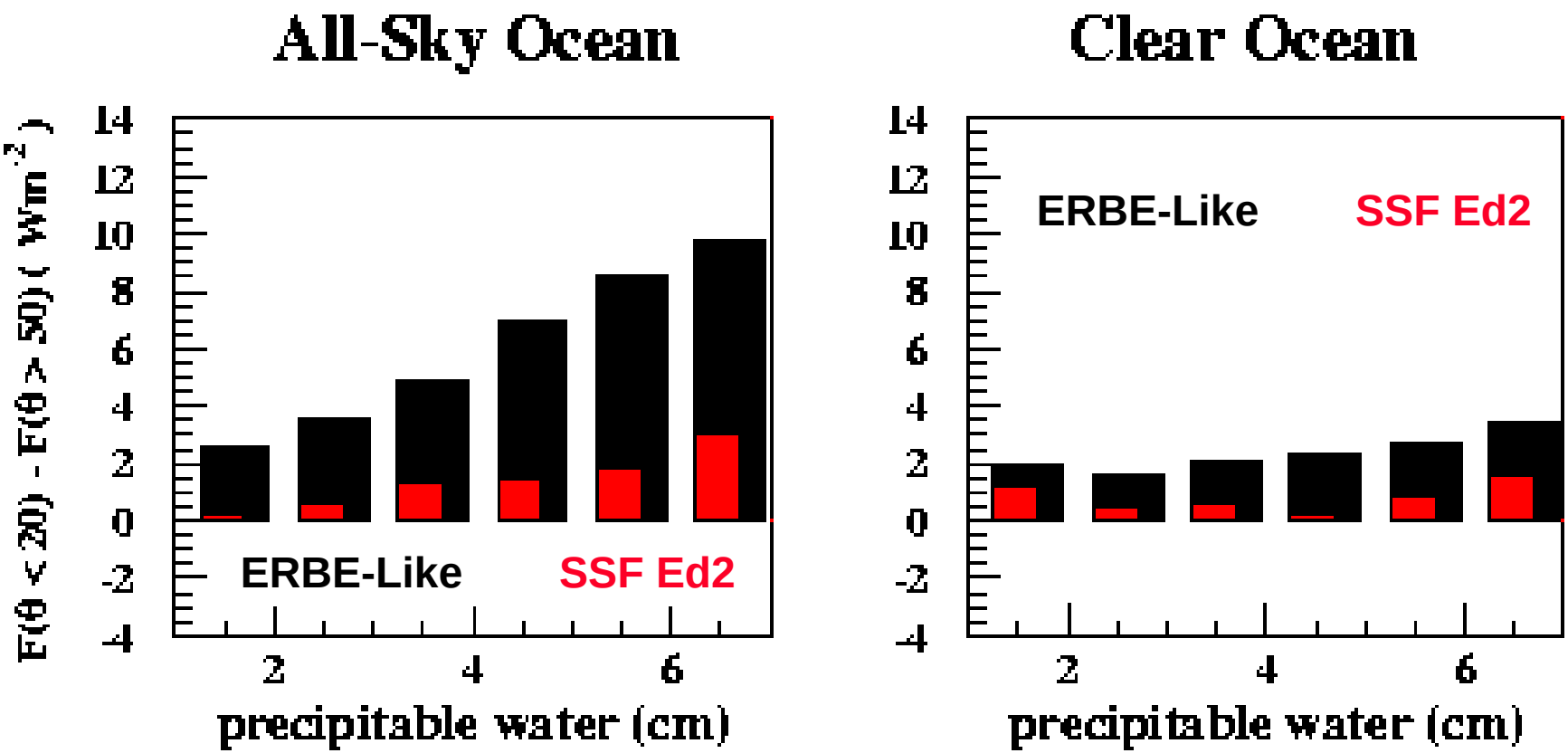
SSF Edition 2 ADM Regional WN Flux Biases: Nighttime
(10°×10° regions)
(W m^{-2})

	Jan-Mar		Jun-Aug	
θ-Range	Δ	σ_Δ	Δ	σ_Δ
$\theta < 50°$	0.34	0.66	0.25	0.86
$\theta < 70°$	0.23	0.22	0.25	0.18
CERES GOAL	-	-	-	-

ERBE-Like – SSF Ed2 LW Flux Difference vs Cloud Emissivity (Overcast; Ocean; θ < 25°; 90 days)

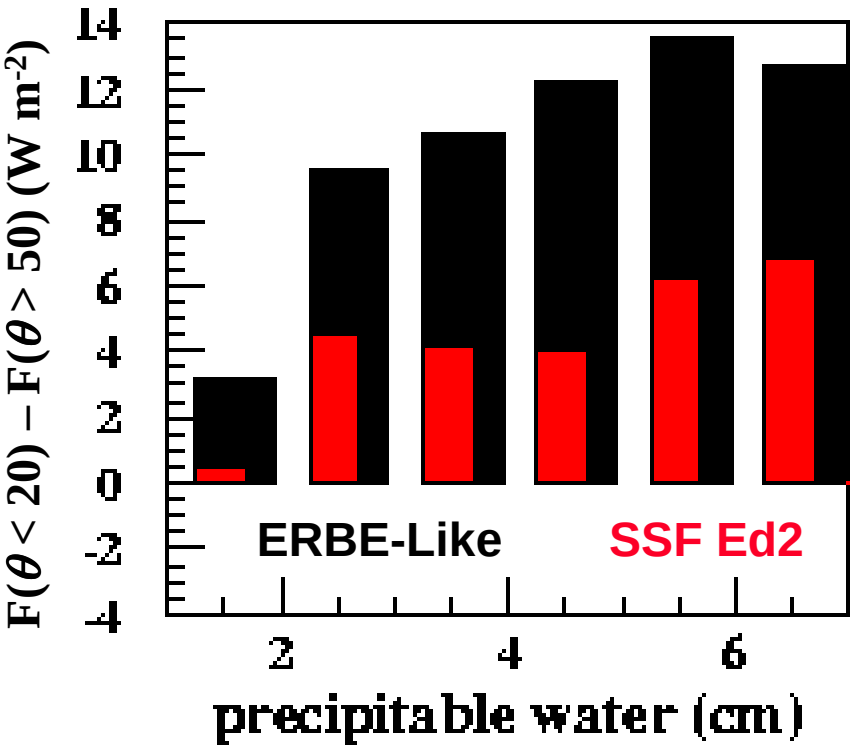


LW Flux Difference [F(θ < 20)-F(θ > 50)] vs Precipitable Water (20°S – 20°N)

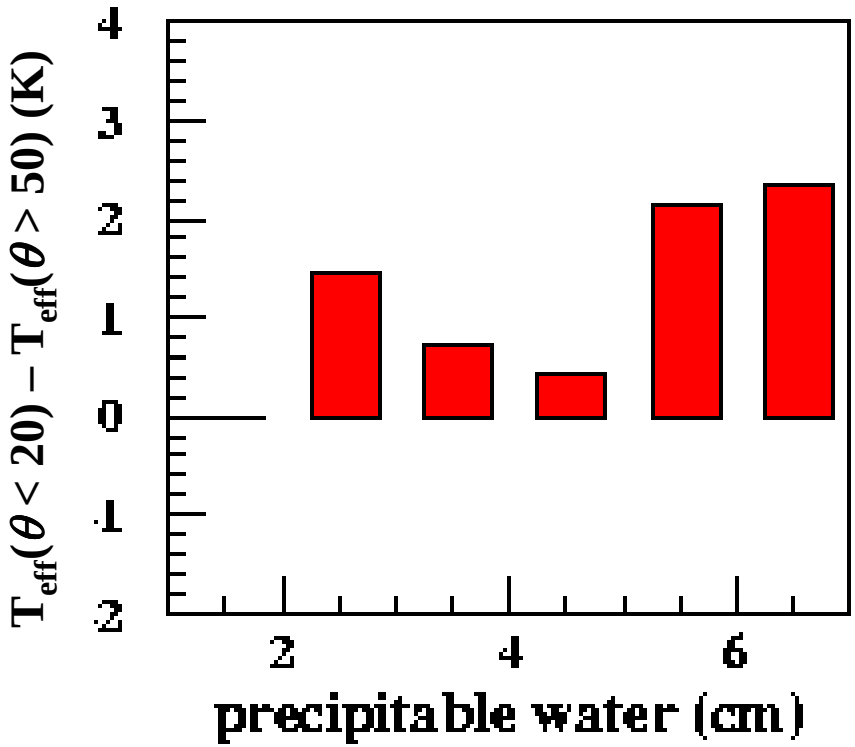


Overcast Ocean (20°S – 20°N)

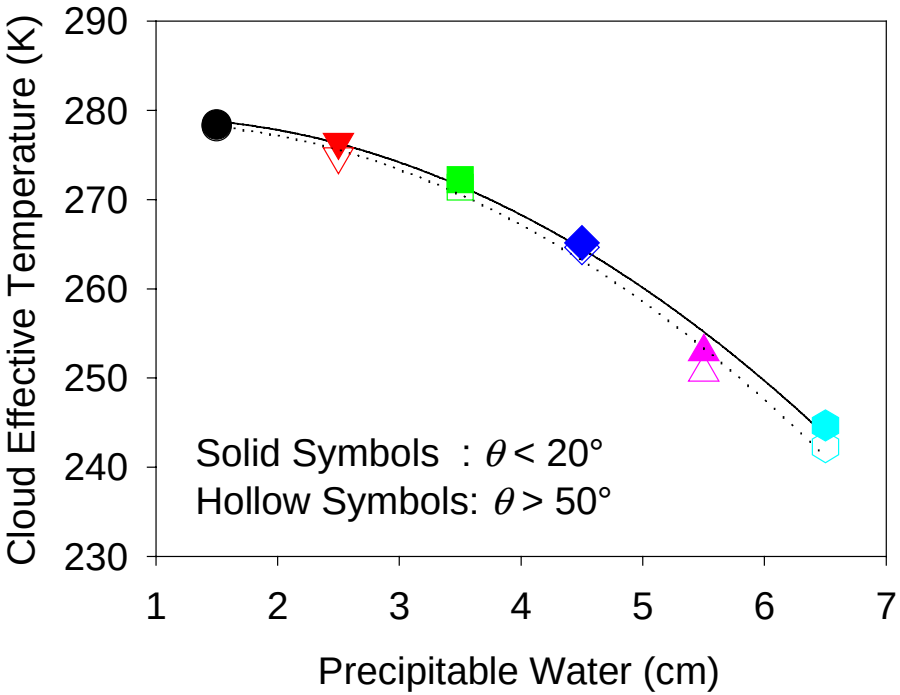
LW Flux Diff vs Precip Water

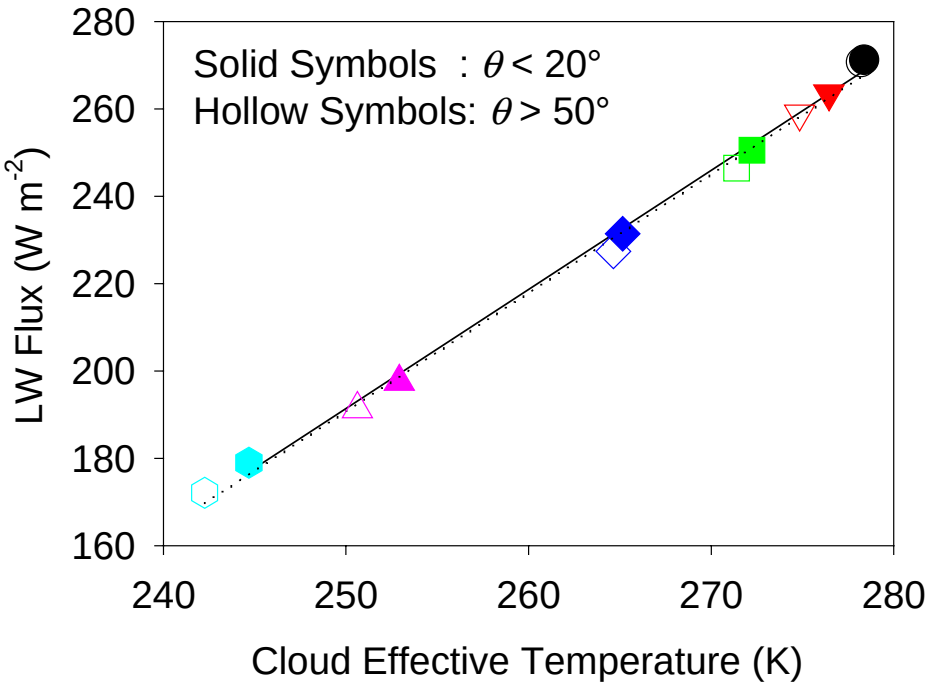


Cld Eff Temp Diff vs Precip Water

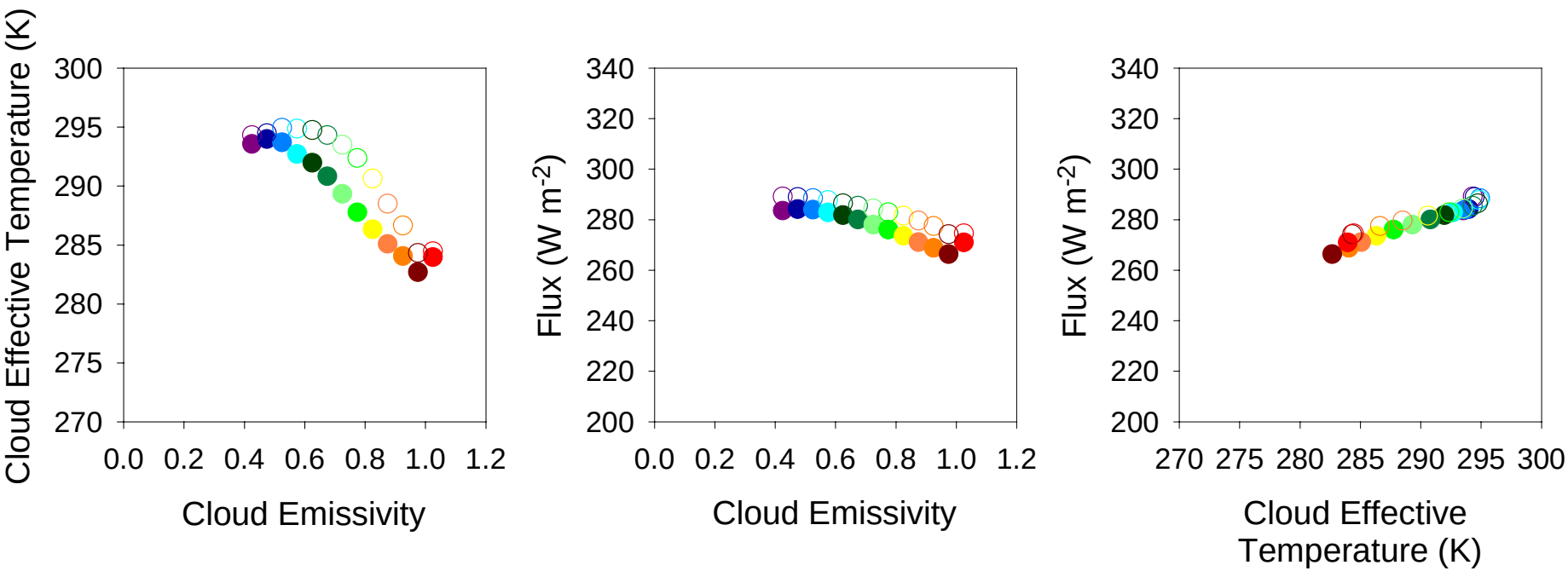


Overcast Ocean (20S - 20N)



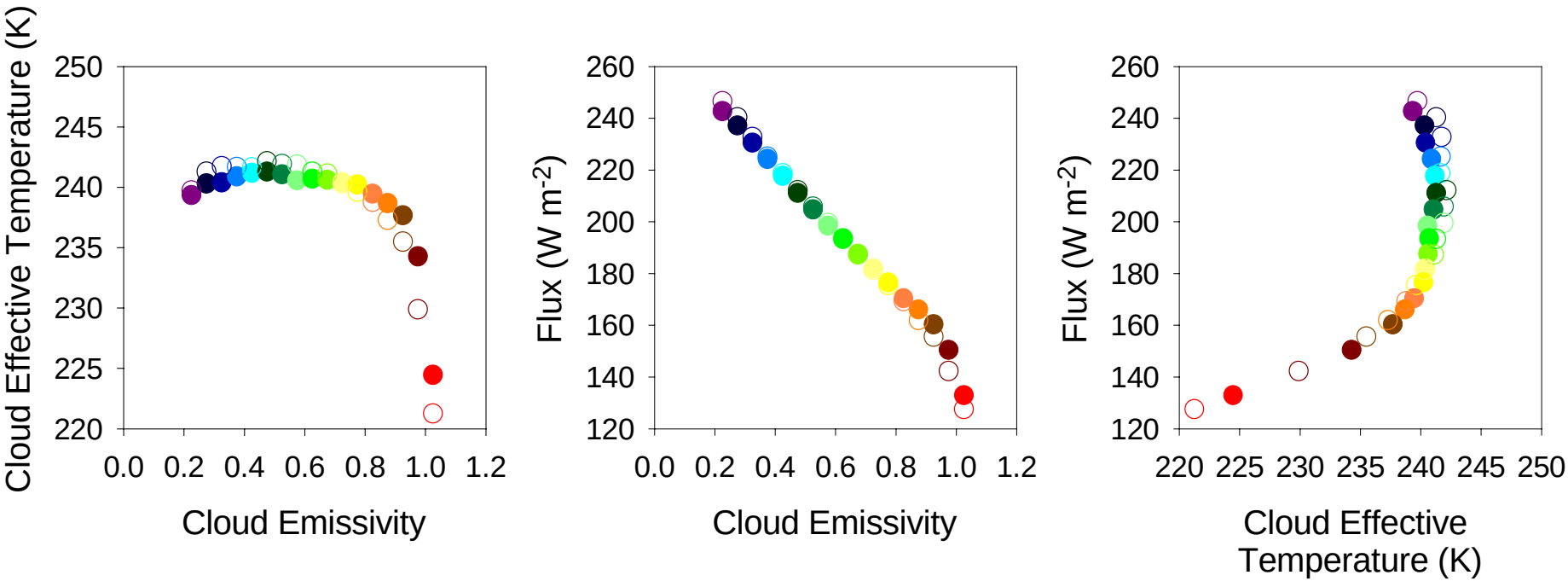


SSF Ed2 LW Flux As Function of Cloud Effective Temperature and Emissivity (Overcast Liquid Water Clouds over Ocean; 20S - 20N)



Solid Symbols : $\theta < 20°$
Hollow Symbols: $\theta > 50°$

SSF Ed2 LW Flux As Function of Cloud Effective Temperature and Emissivity (Overcast Ice Clouds over Ocean; 20S - 20N)



Solid Symbols : $\theta < 20°$
Hollow Symbols: $\theta > 50°$

Summary and Conclusions

- CERES/TRMM SSF Edition 2 Status:

- SW, LW & WN ADMs have been delivered.
- Production of Edition 2 SSFs to begin week of September 24th.
- Archival requires:
  - (i) Science Team approval and
  - (ii) Quality Summary

- Recent Changes to SSF:

- Include all CERES footprints with any VIRS coverage.
- Include footprints over hot land and desert for which VIRS IR radiance saturates.
- Change units of window channel unfiltered radiance & TOA flux to W m^{-2}.

- New ADM web page: *http://asd-www.larc.nasa.gov/Inversion*

- SW TOA Flux Validation:

- SSF Ed2 SW fluxes show less dependence on viewing geometry than ERBE-Like ($\approx$ 10% for ES8; $\approx$ 2% SSF).
- CERES goal for regional mean flux accuracy ($1\sigma < 1$ W m^{-2}) is attained provided full viewing zenith angle coverage < 70° is used. For $\theta < 50$ °, 1σ error is 1.4 W m^{-2}.
- Near-nadir cloudy-sky SSF Ed2 fluxes larger than ERBE-Like at small optical depths and smaller at large cloud optical depths (differences up to $\pm$75 W m^{-2} for $\theta_0 \approx 43$°).
- First estimates of instantaneous flux uncertainties from alongtrack measurements: < 10 W m^{-2} for clear scenes;

  ~20 W m^{-2} for overcast.

  => Further study needed with multiple CERES instruments.

- LW and WN TOA Flux Validation:

- SSF Ed2 LW fluxes show less dependence on viewing geometry than ERBE-Like (9 W m^{-2} for ES8; 1.5 W m^{-2} for Ed2).
- CERES goal for regional mean LW flux accuracy ($1\sigma < 0.5$ W m^{-2}) is almost reached. 1σ error is $\approx$ 0.56 W m^{-2} during daytime.
- Nighttime LW flux shows a 0.5 W m^{-2} mean bias with 1σ of $\approx$ 0.4 W m^{-2} .
- WN 1σ flux error is 0.3 W m^{-2} . Nighttime WN flux bias is 0.25 W m^{-2}.
- Near-nadir cloudy-sky SSF Ed2 LW fluxes larger than ERBE-Like at small emissivity but comparable for emissivity close to 1.0 (differences at small ε up to $\pm$25 W m^{-2}).
- SSF Ed2 LW flux errors as a function of precip water are a factor of 3-4 smaller than ERBE-Like.

Future Work (Terra)

- Increase angular resolution of ADMs.
- Land SW ADMs stratified by vegetation index.
- Empirical SW, LW and WN ADMs over snow.
- Use of multi-CERES instruments for instantaneous flux errors.
- Determine flux errors by cloud type, cloud and clear-sky parameters.
- Improve theoretical tools for ADM development and comparisons between observations and theory.