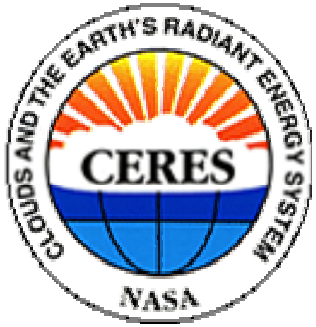
TOA Radiative Flux Estimation From CERES Angular Distribution Models

Norman G. Loeb

Hampton University/NASA Langley Research Center

Hampton, VA



Acknowledgements: K. Loukachine, S. Kato, N. M. Smith

January 29, 2003

Outline

1. Introduction

2. TOA flux retrieval strategy – ADM definition

3. CERES/TRMM Validation Results

4. Plans for CERES/Terra ADMs

5. Summary

Top-of-Atmosphere Radiation Budget

(Incoming Solar = Outgoing Longwave):

$$(1-A)\frac{S_o}{4} = \sigma T_e^4 \approx 208 + 2T_s$$

$A = Planetary\ Albedo$

$S_o = Solar\ Irradiance$

$T_e = Earth\ Radiative\ Temperature$

$T_s = Equilibrium\ Surface\ Temperature$

$$\Delta T_s = -\frac{1}{2}\left(\frac{S_o}{4}\right)\Delta A \approx -0.5^oC\left(100\frac{\Delta A}{A}\right)$$

1% relative error in *A*

$\Rightarrow$ ≈1 W m^{-2} flux error $\Rightarrow$ ≈0.5°C error in T_s

2xCO_2 => +4 W m^{-2}

Instantaneous Fluxes at TOA and Angular Distribution Models

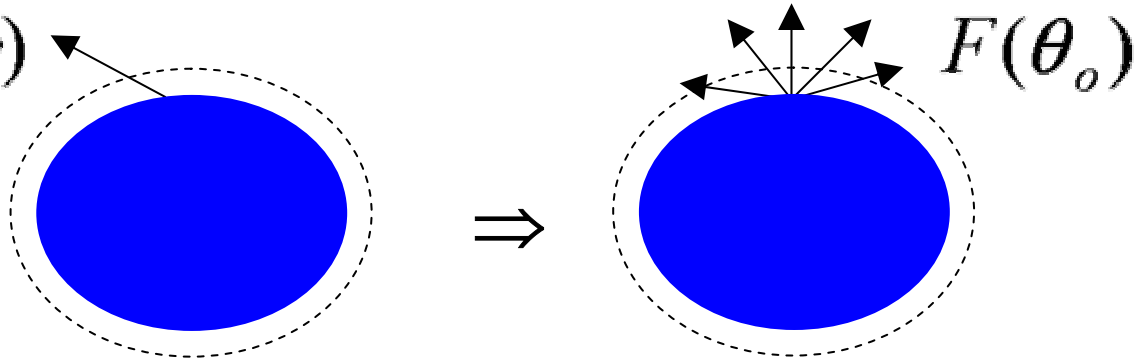
CERES Radiance Measurement

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

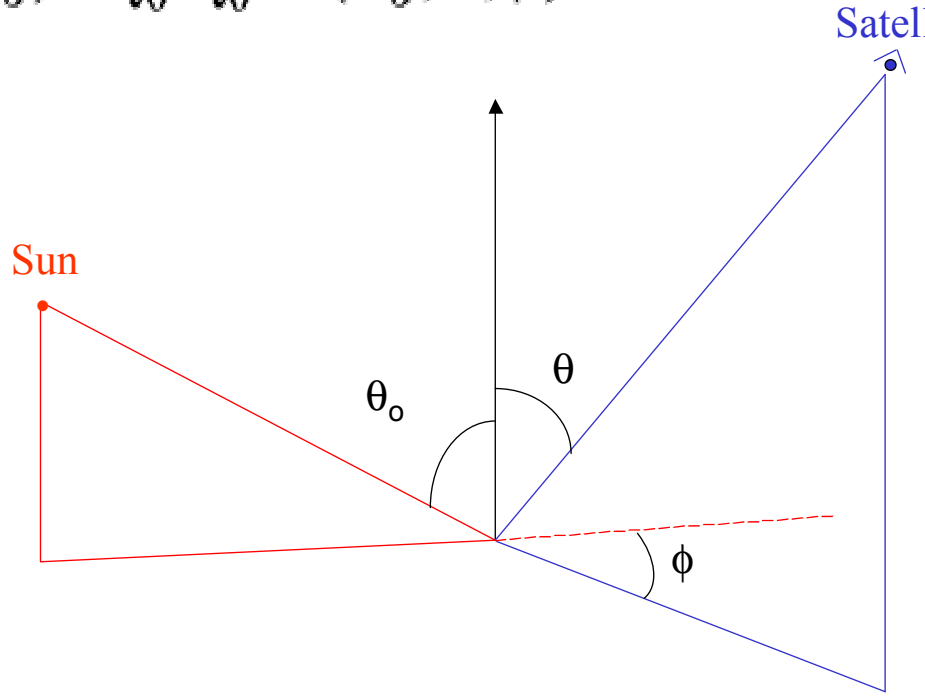
TOA Flux Estimate

$F(\theta_o)$

SW
LW
WN



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



Instantaneous Fluxes at TOA and Angular Distribution Models

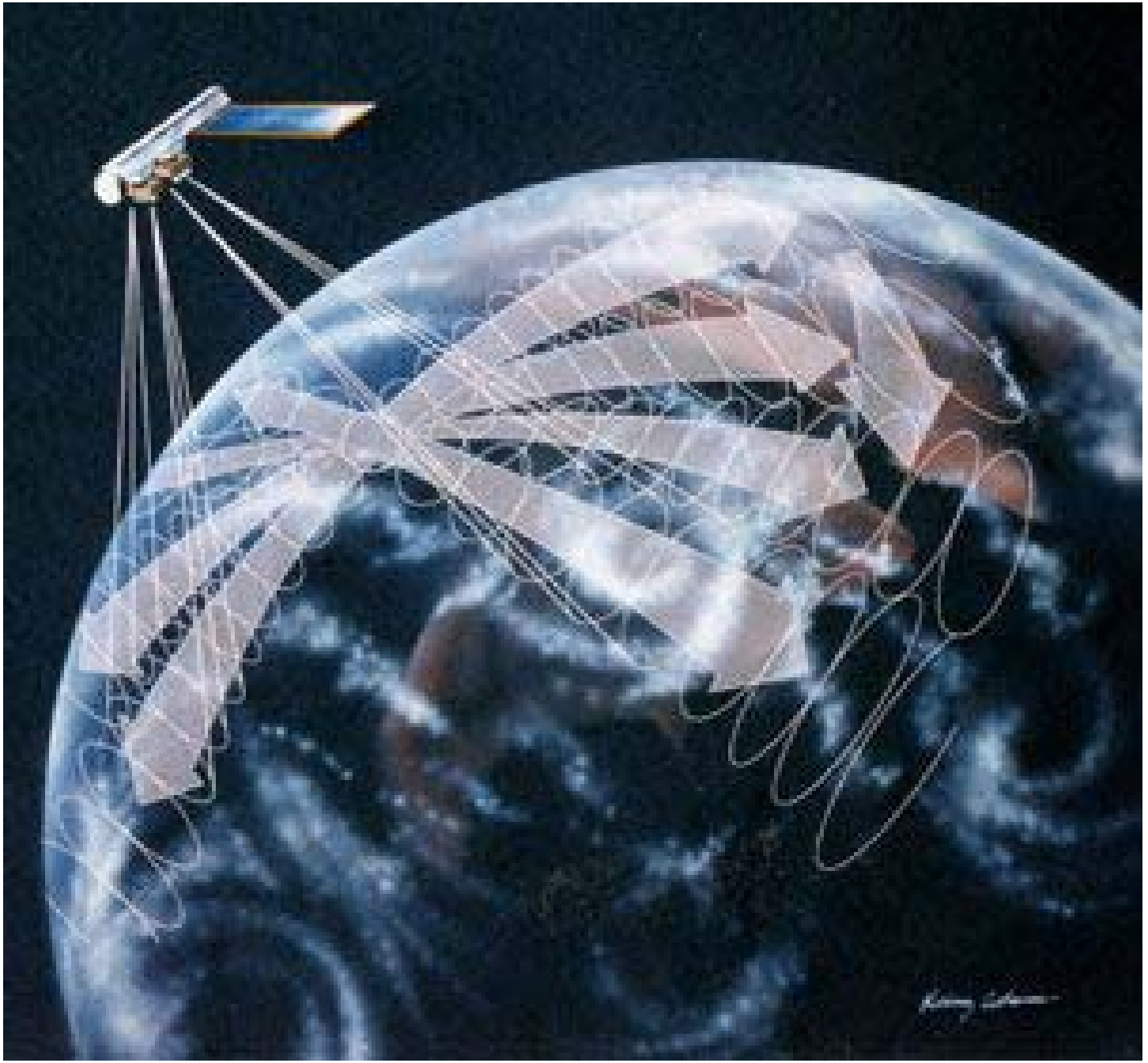
TOA flux estimate from CERES radiance:

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

where,

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

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



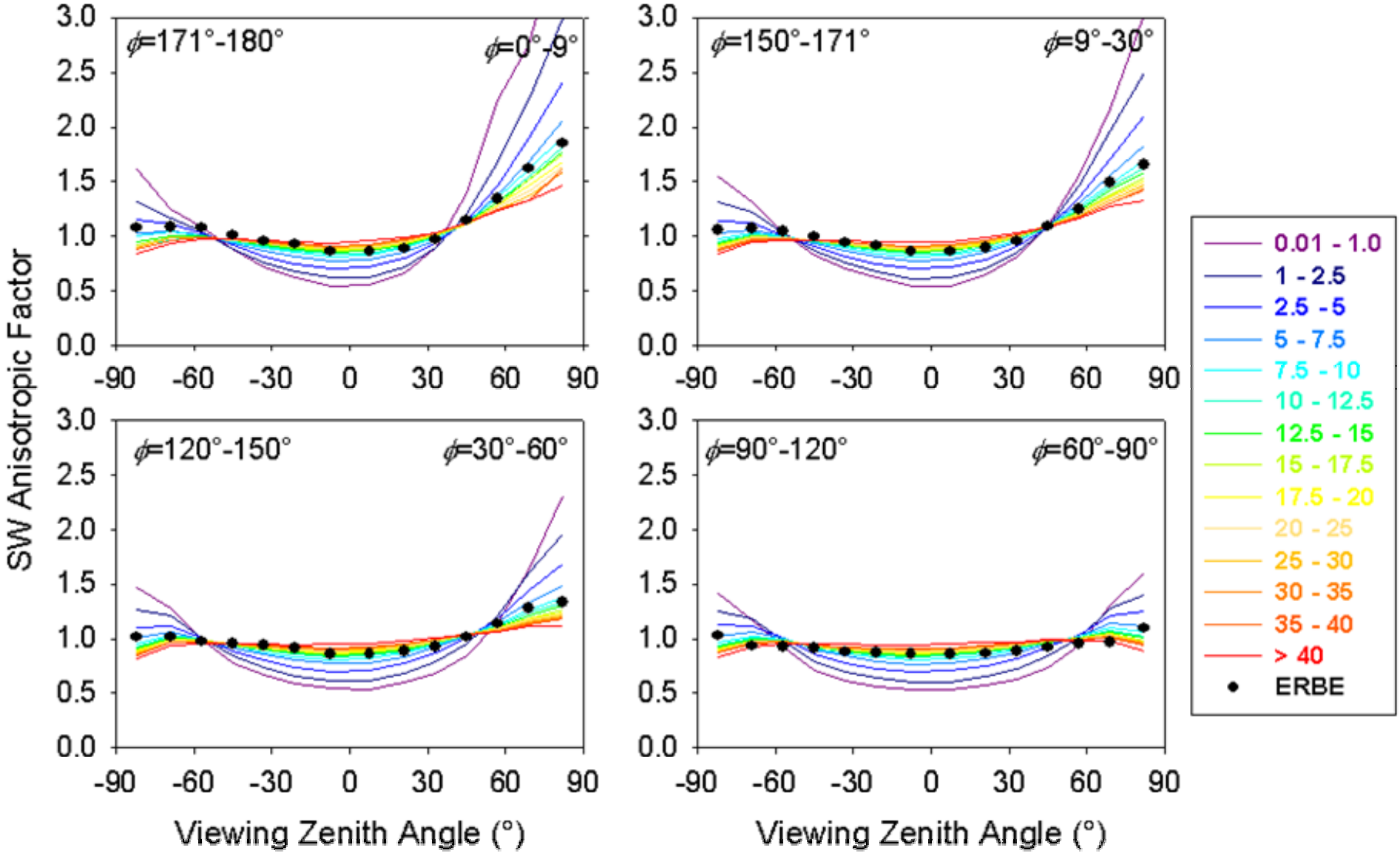
ADM Scene Identification

- The main reason for defining ADMs by scene type is to reduce the error in the albedo estimate.

  => Earth scenes have distinct anisotropic characteristics which depend on their physical and optical properties. (e.g. thin vs thick clouds; cloud-free, broken, overcast etc.).

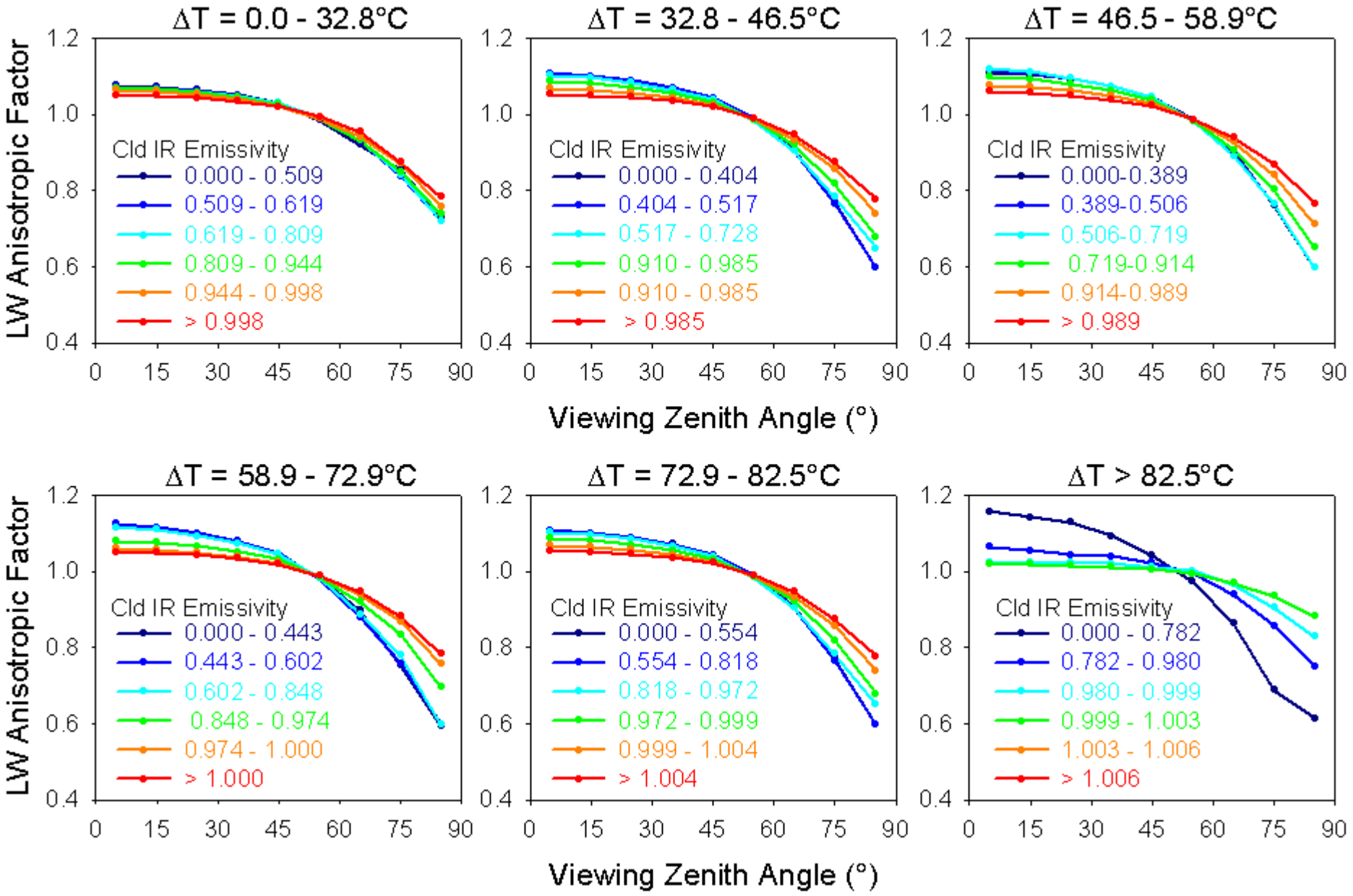
  => Scene identification must be self-consistent. Biases in cloud property retrievals (e.g. due to 3D cloud effects) should not introduce biases in flux/albedo estimates.

CERES/TRMM Overcast Ice Cloud ADMs vs ERBE (θ_o=53.1-60)



Overcast LW ADMs

(Precipitable Water 4.63 – 10.00 cm)



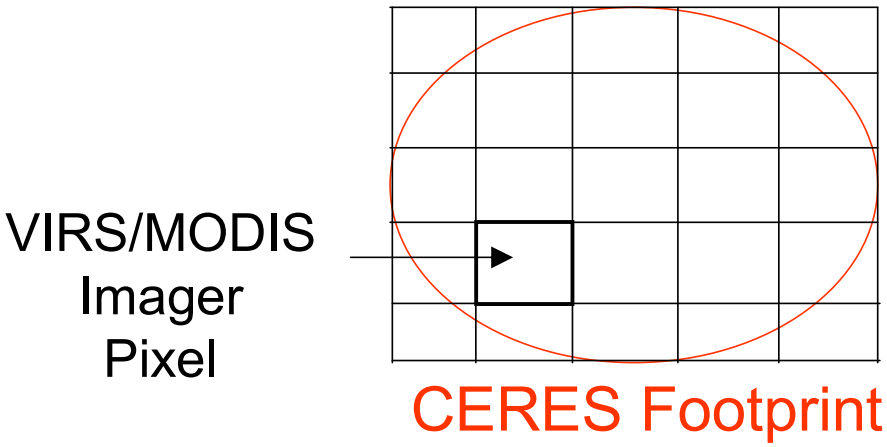
Anisotropic Model Scene Type Stratification

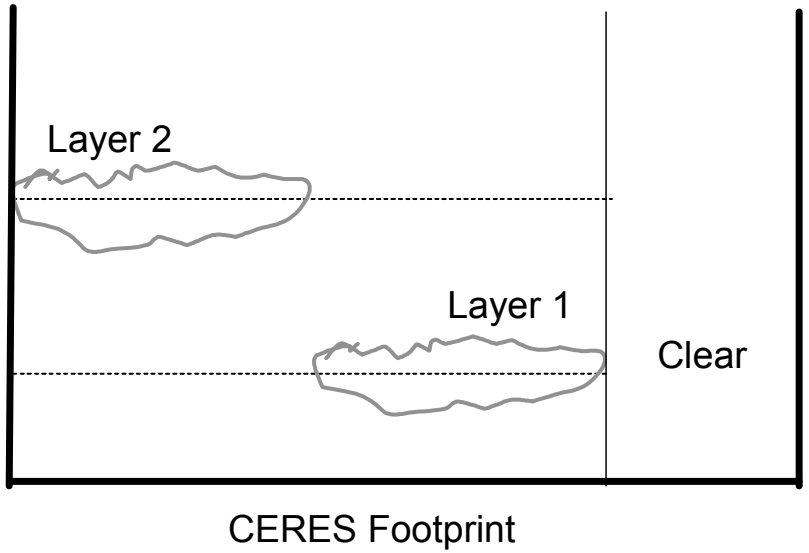
Spacecraft/Mission	Cloud	Surface Type	Total
TIROS 2, 3, 4	N/A	N/A	isotropy
TIROS 7 (Arking and Levine, 1967)	Global	Global	1
Nimbus 2, 3 (Rashke et al. 1973)	Cloud/Land	Ocean Snow	3
Nimbus-6, 7 (Taylor and Stowe, 1984; Jacobowitz et al., 1984)	All Cloud	Ocean Land Snow/Ice	4
ERBE (Smith et al., 1986; Suttles et al., 1988)	Clear Partly cloudy Mostly cloudy Overcast	Ocean Land Desert Snow Land-Ocean Mix	12

CERES Single Scanner Footprint (SSF) Product

- Coincident CERES radiances and imager-based cloud and aerosol properties.
- Use VIRS (TRMM) or MODIS (Terra, Aqua) to determine 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 : Albedo, Skin Temperature, Aerosol optical depth, Emissivity





Scene Types for CERES/TRMM SW ADMs

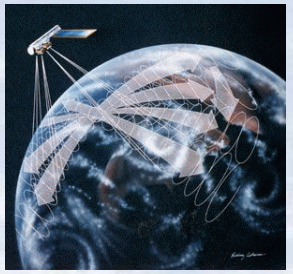
ADM Category		Scene Type Stratification	Actual Total
Clear	Ocean	- 4 Wind Speed Intervals	4
	Land	- 2 IGBP Type Groupings	2
	Desert	- Bright and Dark	2
	Snow	- Theoretical	1
Cloud	Ocean	- Liquid and Ice - 12 Cloud Fraction Intervals - 14 Optical Depth Intervals	62 (L) 53 (I)
	Land	- 2 IGBP Type Groupings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

Scene Types for CERES/TRMM LW and WN ADMs

ADM Category		Parameter Stratification	Total
Clear	Ocean	3 Precipitable Water	15
		5 Vertical Temperature Change	
	Land	3 Precipitable Water	15
		5 Vertical Temperature Change	
	Desert	3 Precipitable Water	15
		5 Vertical Temperature Change	
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	126
		7 ΔT (Sfc-Cloud)	
		6 IR Emissivity	

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

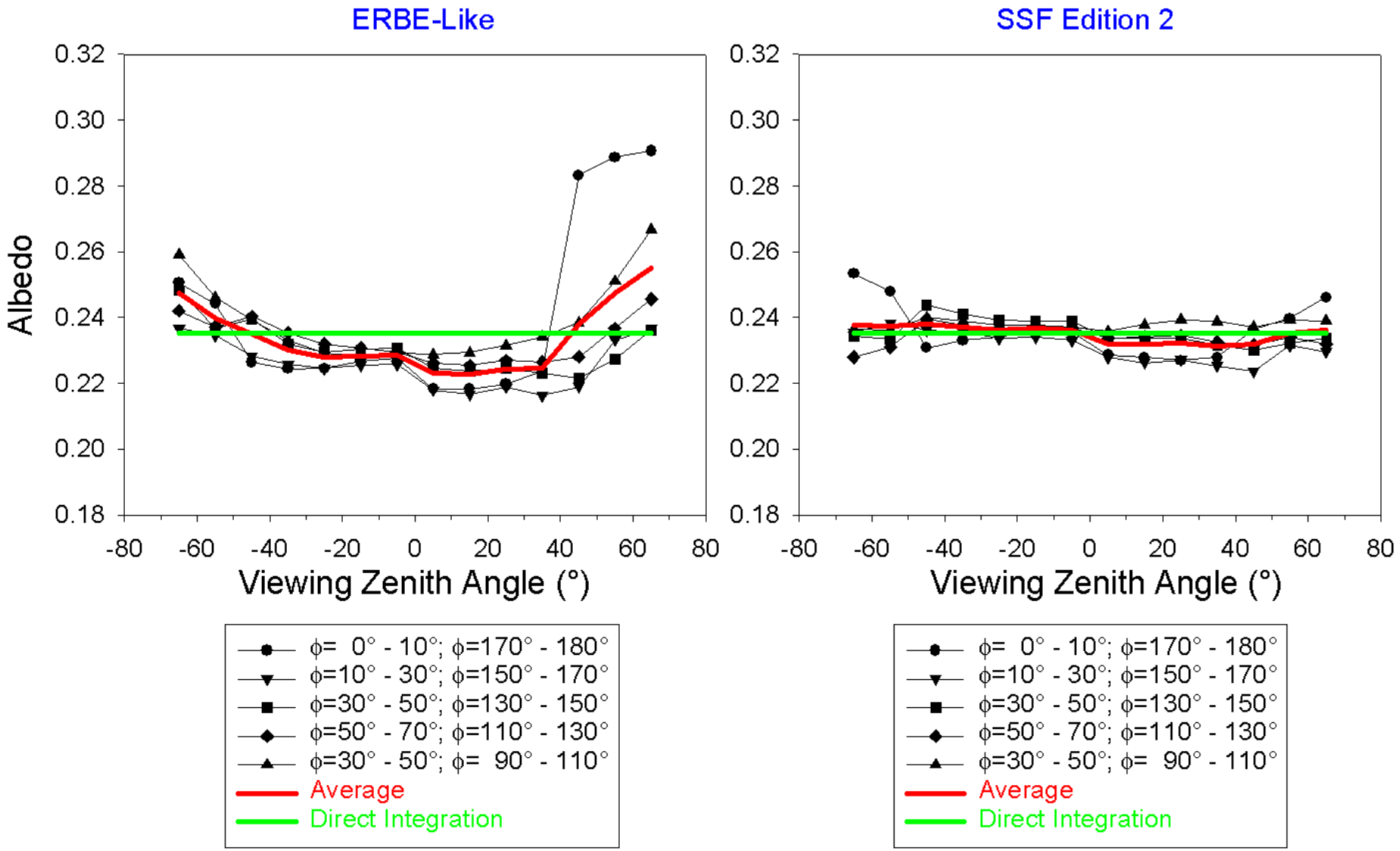
Current Research

Relevant Links

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

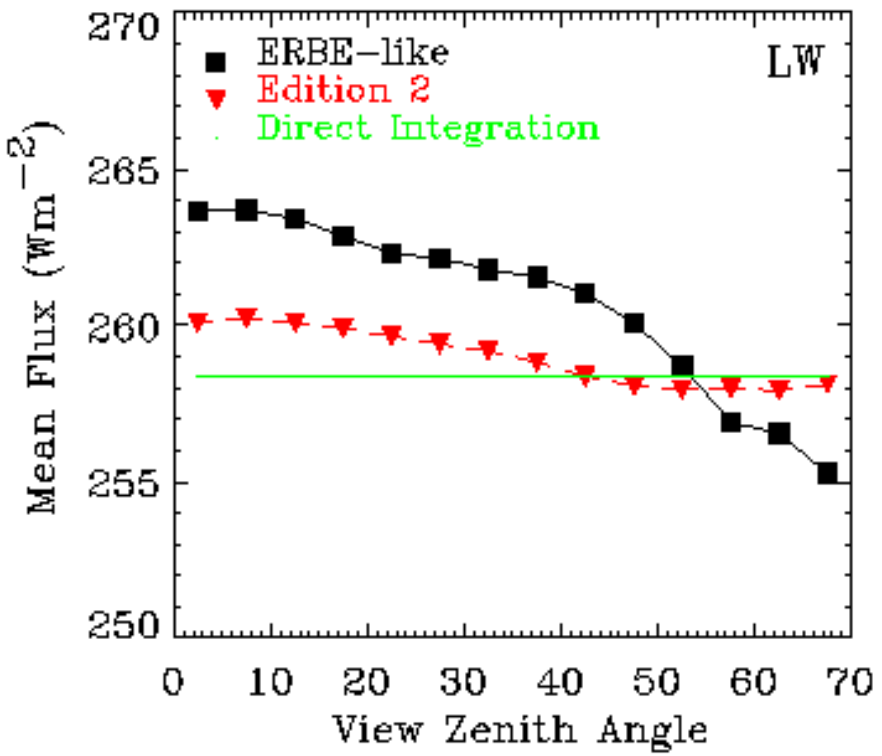
CERES/TRMM Validation Results

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

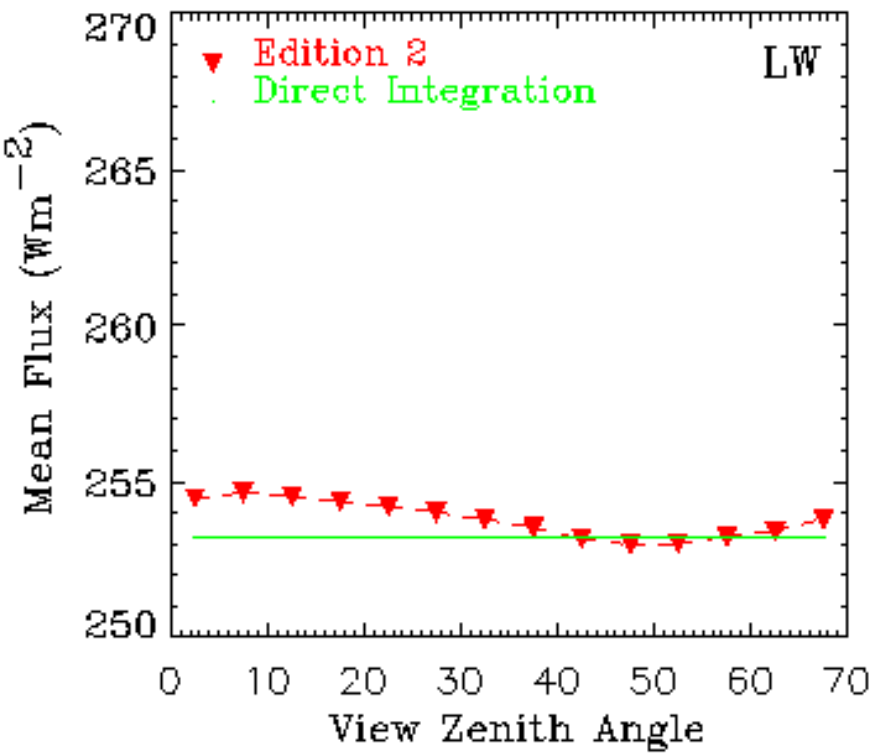


Mean LW Flux vs Viewing Zenith Angle (Jan-Mar 1998)

Daytime

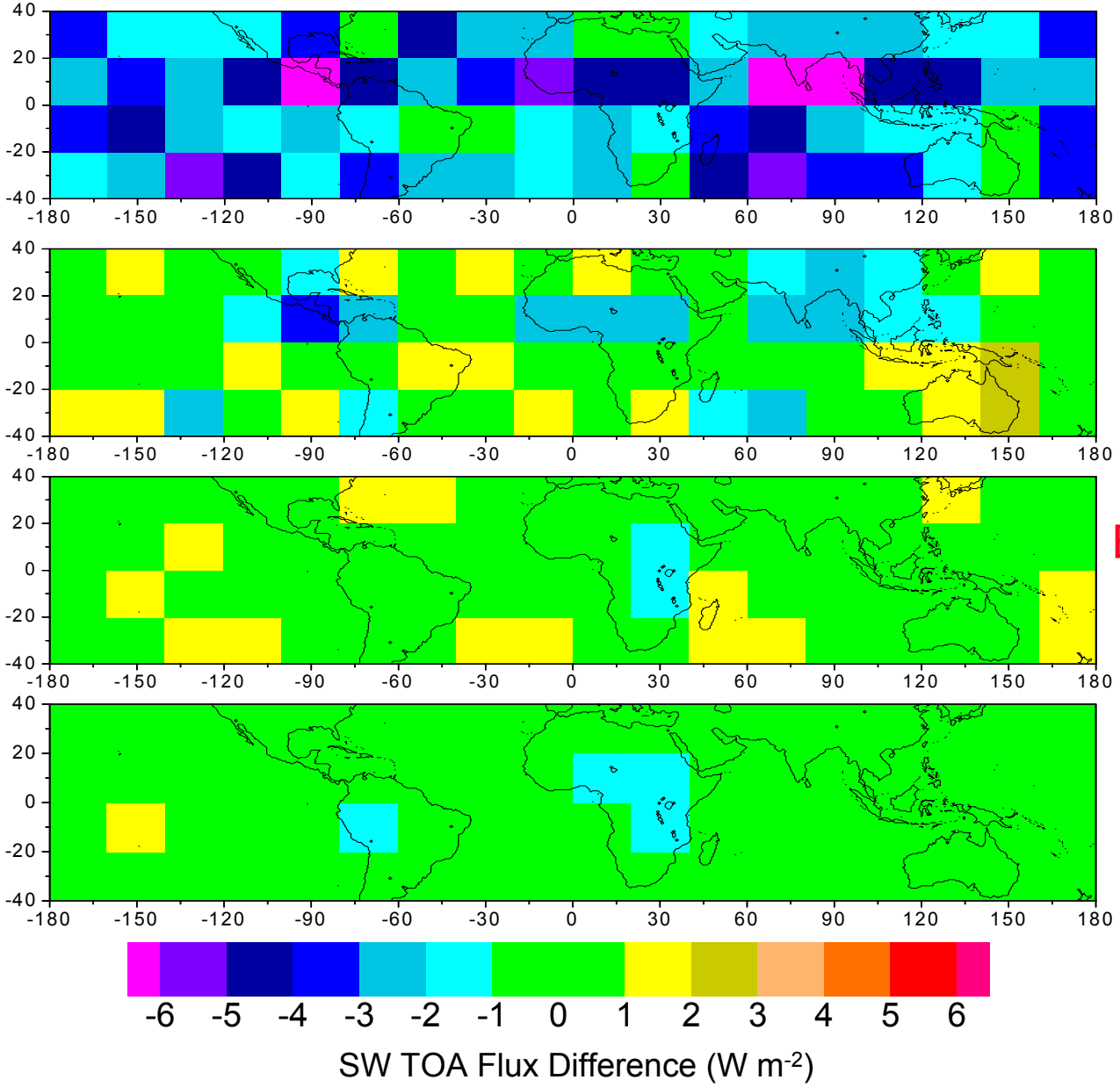


Nighttime



ADM Mean Regional SW TOA Flux Biases

(March 1998 Solar Zenith Angle Sampling)



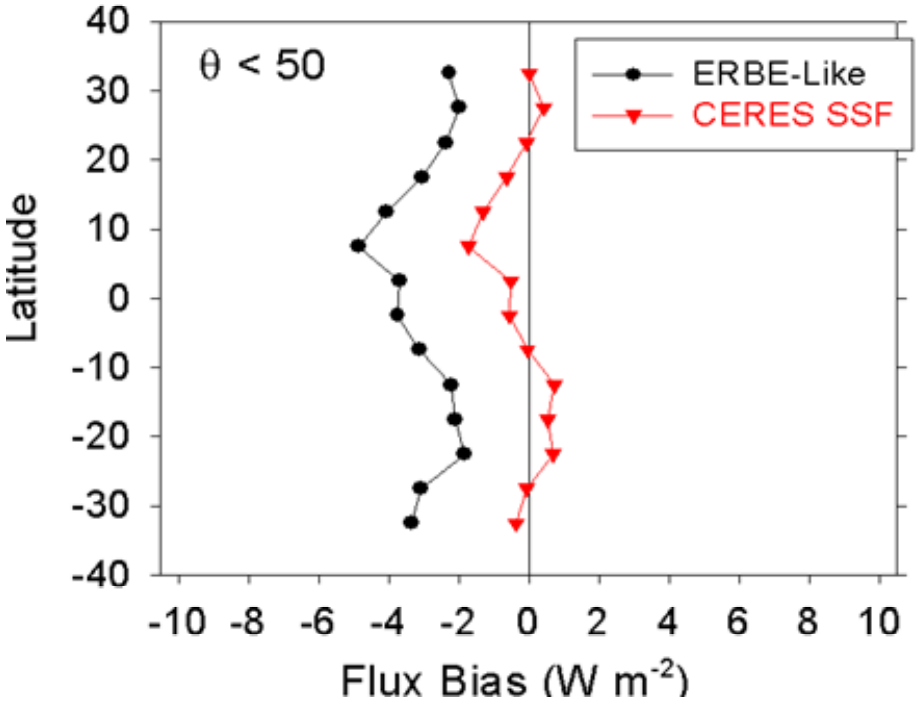
ERBE-Like minus DI
$\theta < 50°$

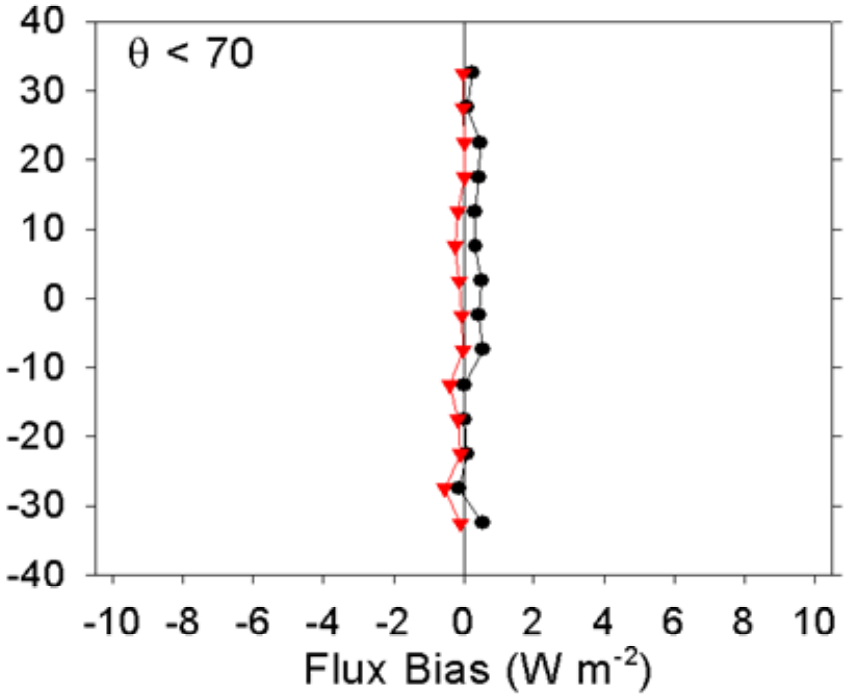
SSF minus DI
$\theta < 50°$

ERBE-Like minus DI
$\theta < 70°$

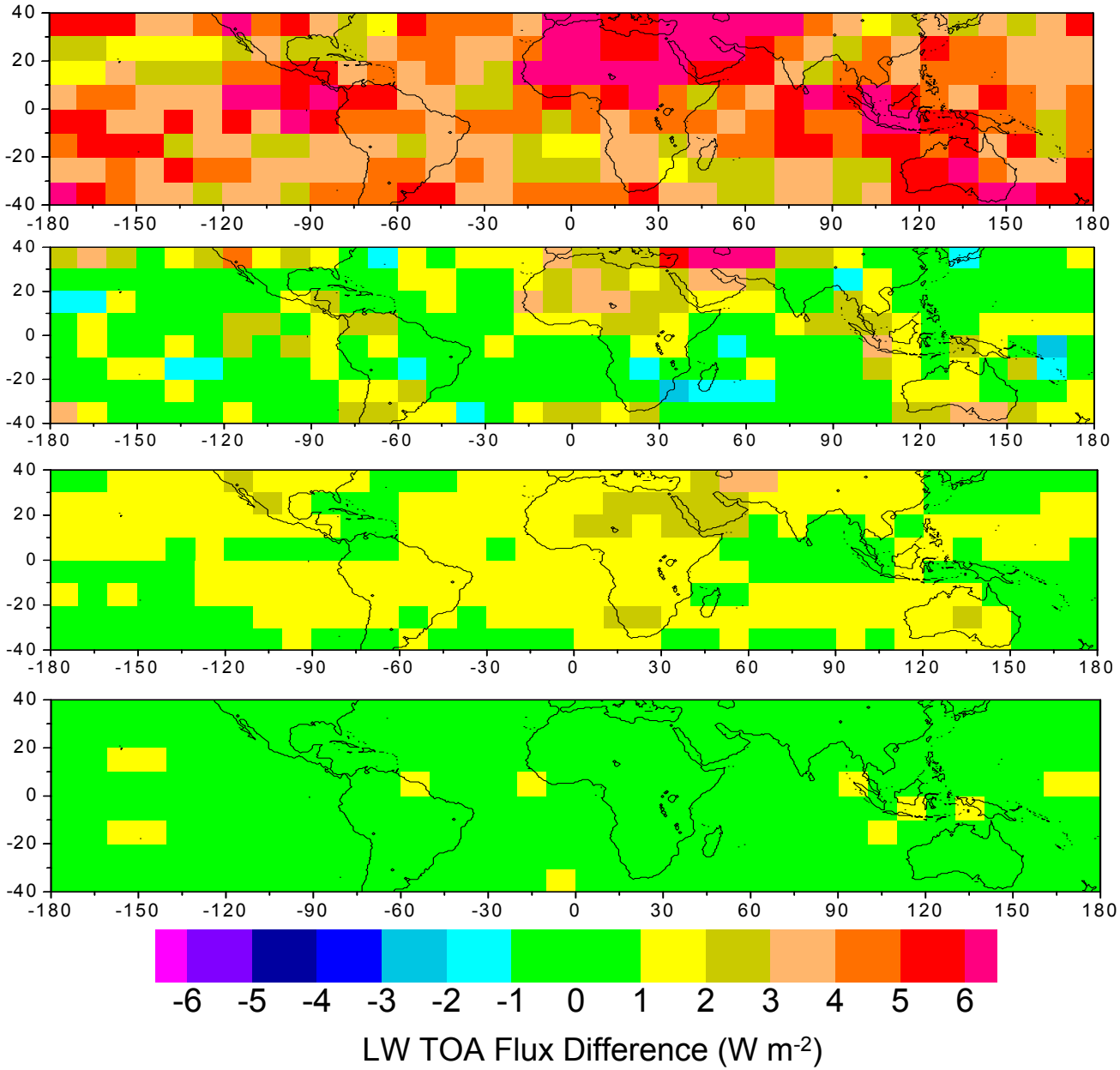
SSF minus DI
$\theta < 70°$

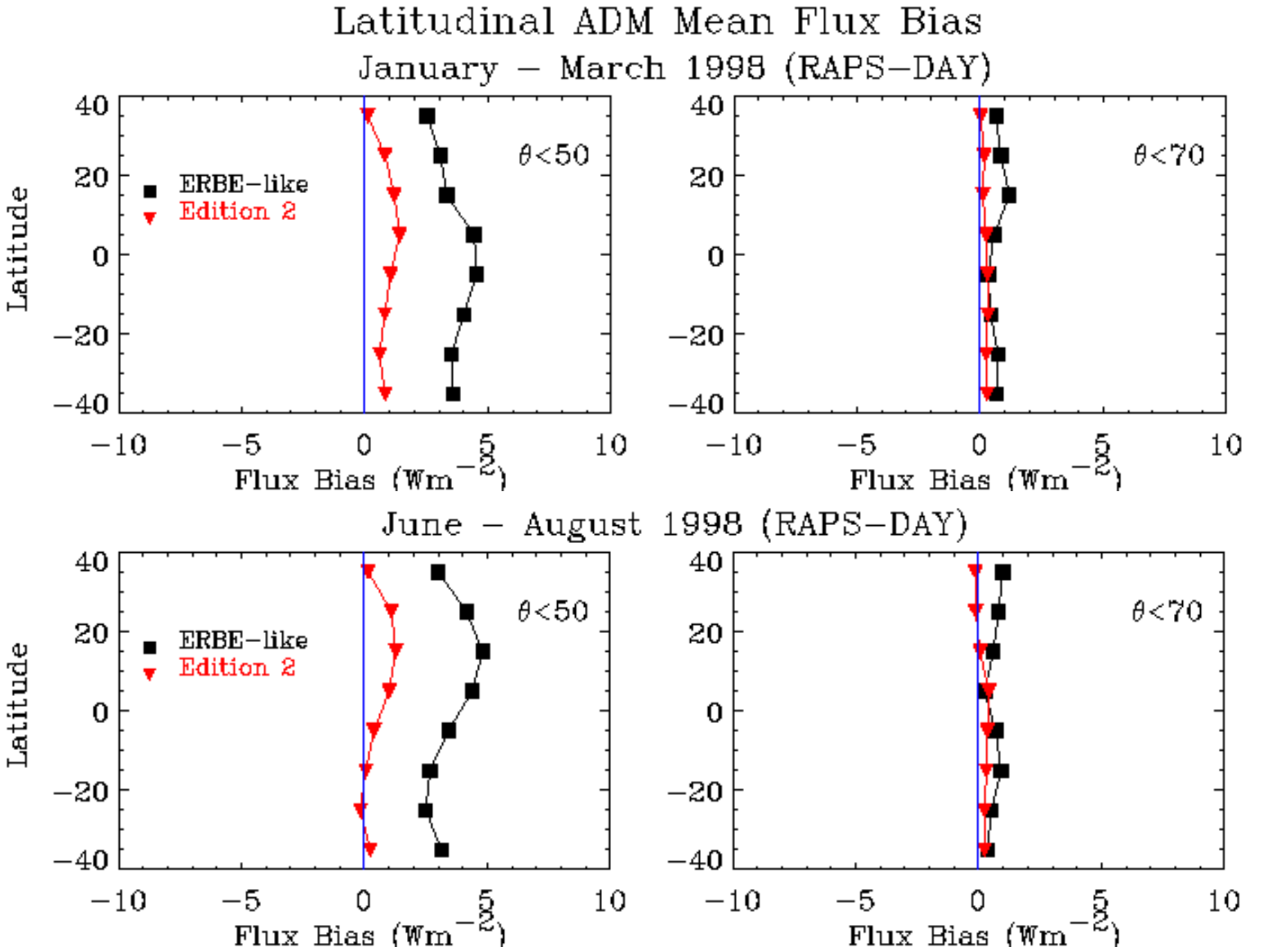
Latitudinal ADM Mean Flux Bias
(March 1998 Solar Zenith Angle Sampling)





ADM Mean Regional LW TOA Flux Biases



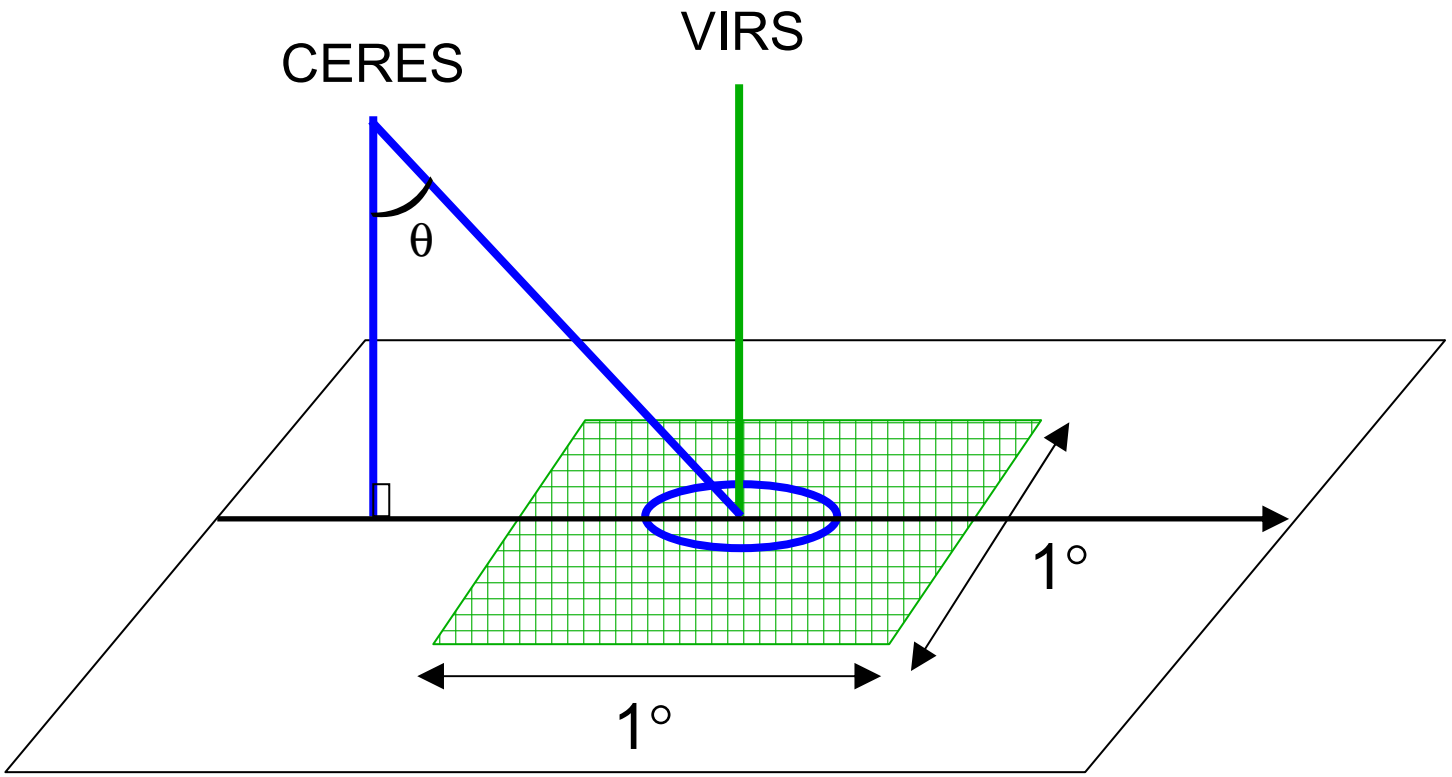

Latitudinal ADM Mean Flux Bias
January – March 1998 (RAPS–DAY)
June – August 1998 (RAPS–DAY)
ERBE–like
Edition 2
θ<50
θ<70
Latitude
Flux Bias (Wm⁻²)
40
20
0
−20
−40
−10
−5
0
5
10

Mean Regional SW and LW TOA Flux Bias (Δ) and *RMS* Errors (W m^{-2}) for ERBE-Like and CERES/TRMM SSF TOA Fluxes

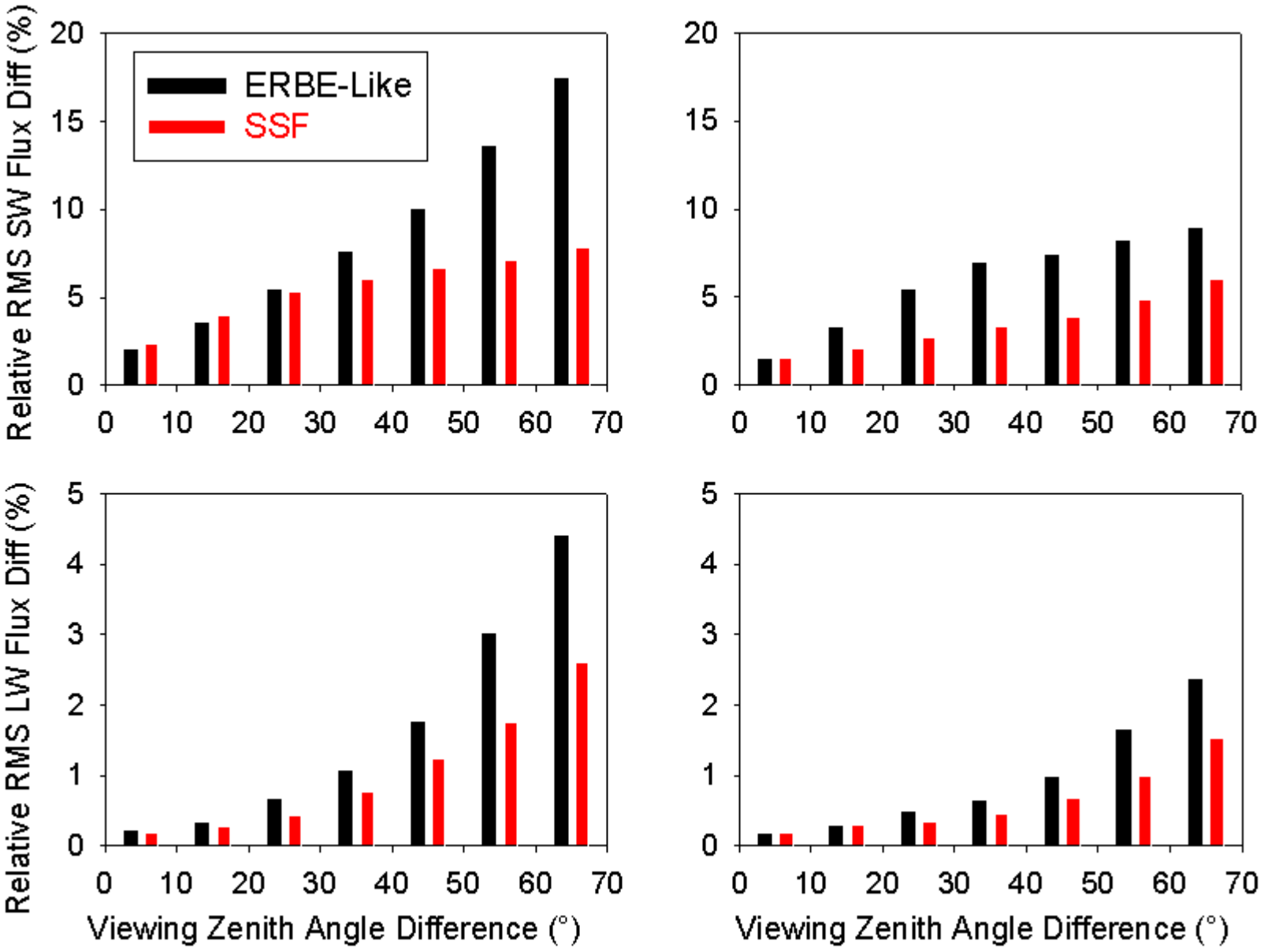
	SW			
	ERBE-Like		SSF	
θ-range	Δ	RMS	Δ	RMS
θ < 50°	-2.73	3.12	0.03	1.42
θ < 70°	0.43	0.82	-0.06	0.51
	LW			
	ERBE-Like		SSF	
θ-range	Δ	RMS	Δ	RMS
θ < 50°	4.35	4.60	0.87	1.62
θ < 70°	1.22	1.33	0.29	0.49

1° Regional Instantaneous SW TOA Flux Consistency Test

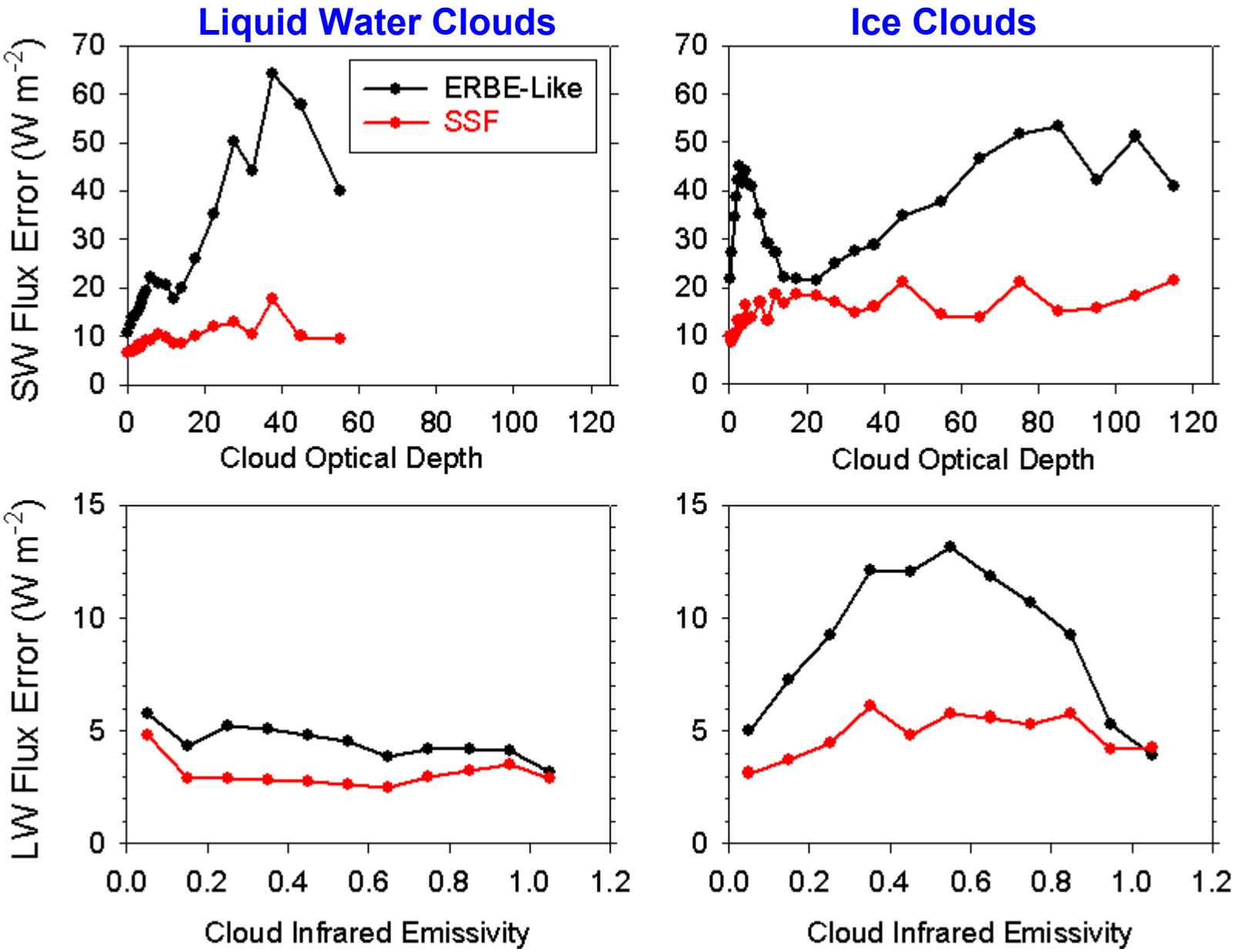
Objective: Compare ADM-derived TOA fluxes over 1° regions from different viewing geometries. Are TOA fluxes consistent?



Relative RMS Difference Between TOA Fluxes from Coincident VIRS Nadir and CERES Off-Nadir Radiances



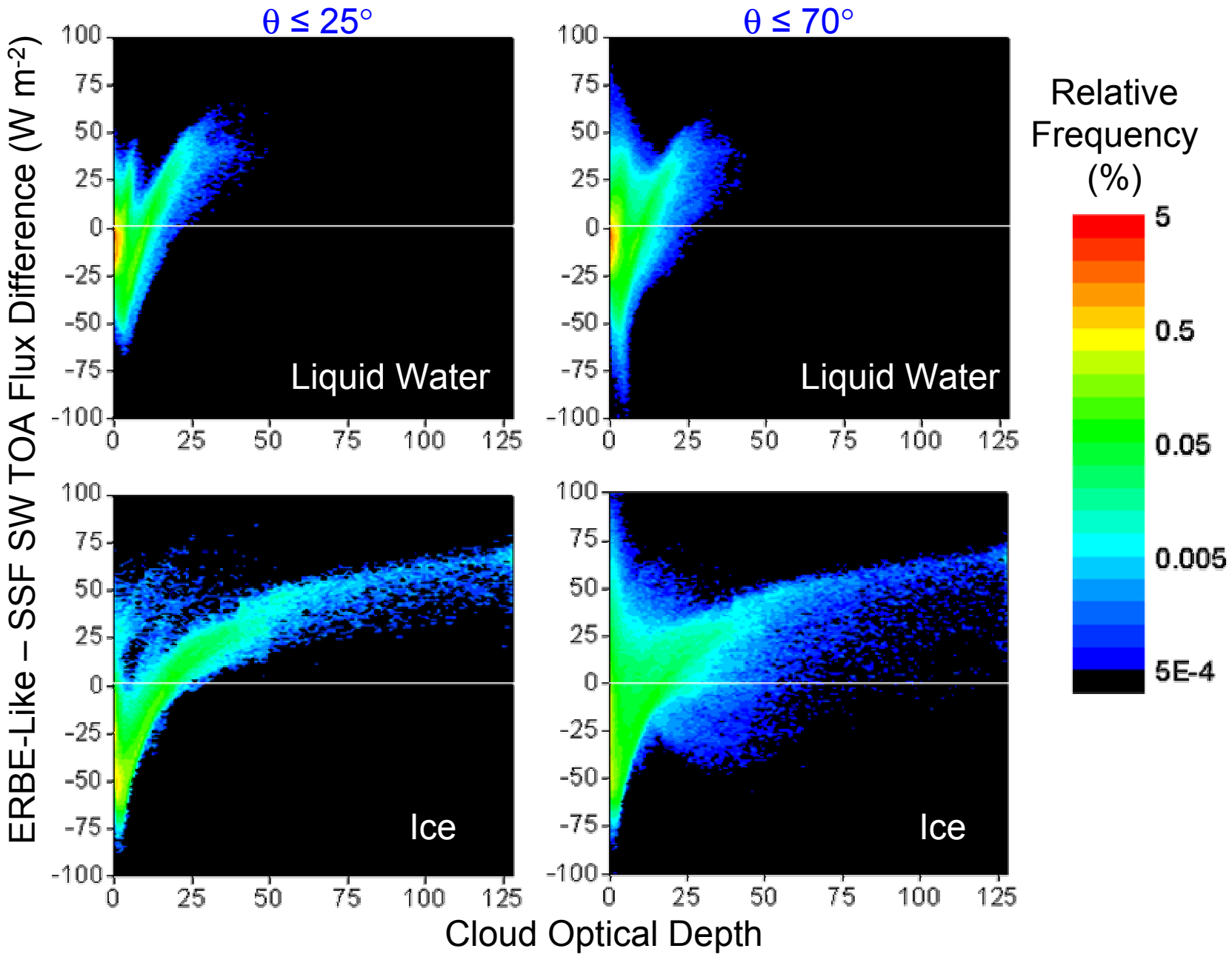
Estimated Regional SSF and ERBE-like Instantaneous TOA Flux Errors



Estimated Regional Instantaneous SW and LW TOA Flux Errors (W m^{-2}) in All-Sky and Clear-Sky Conditions

Channel	All-Sky		Clear-Sky	
	ERBE-Like	SSF	ERBE-Like	SSF
SW	22.2	9.8	11.2	7.9
LW	5.8	3.5	3.7	2.4

ERBE vs CERES SW TOA Flux by Cloud Type



CERES/Terra ADM Development

New ADMs for Terra: Approaches Being Considered

1. Shortwave:

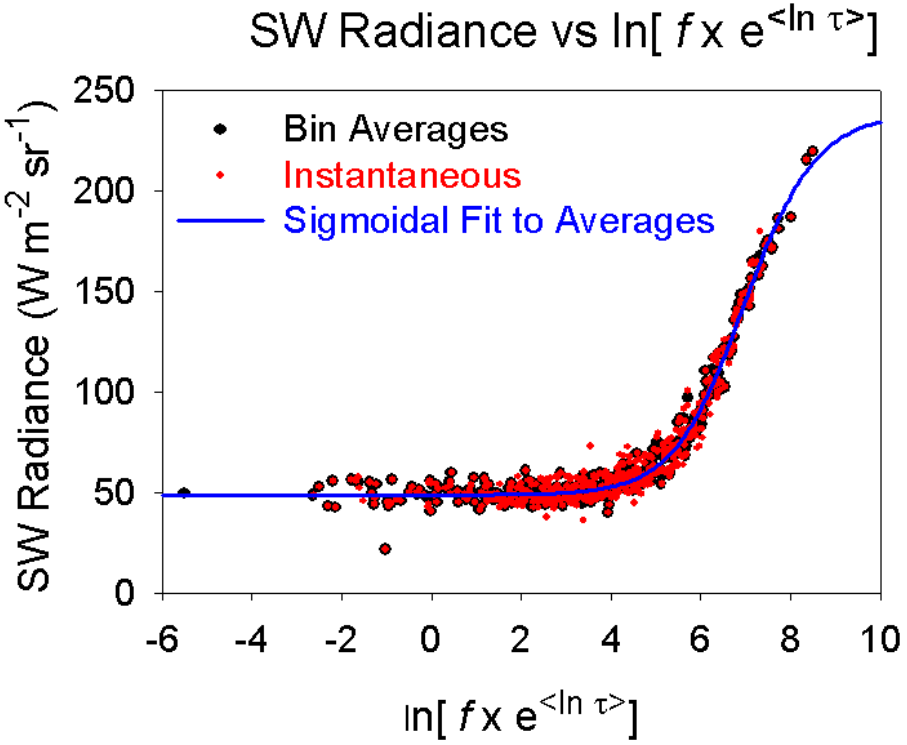
- Increase resolution of angular bins to 2°
- Clear Ocean: Similar approach as on CERES/TRMM
  => Wind speed-dependent ADMs with theoretical correction for aerosol optical depth variations.
- Clouds over Ocean: Continuous scene type using sigmoidal functional fits to data.
- Clear Land: Stratify by IGBP type + vegetation index + τ_{aer}
  => Is there any change in anisotropy?
- Clouds over Land: Continuous scene type using sigmoidal functional fits to data.
- Clear Snow: Stratify by Permanent Snow, Fresh Snow, Sea Ice
- Clouds over Snow: Cloud fraction and snow type

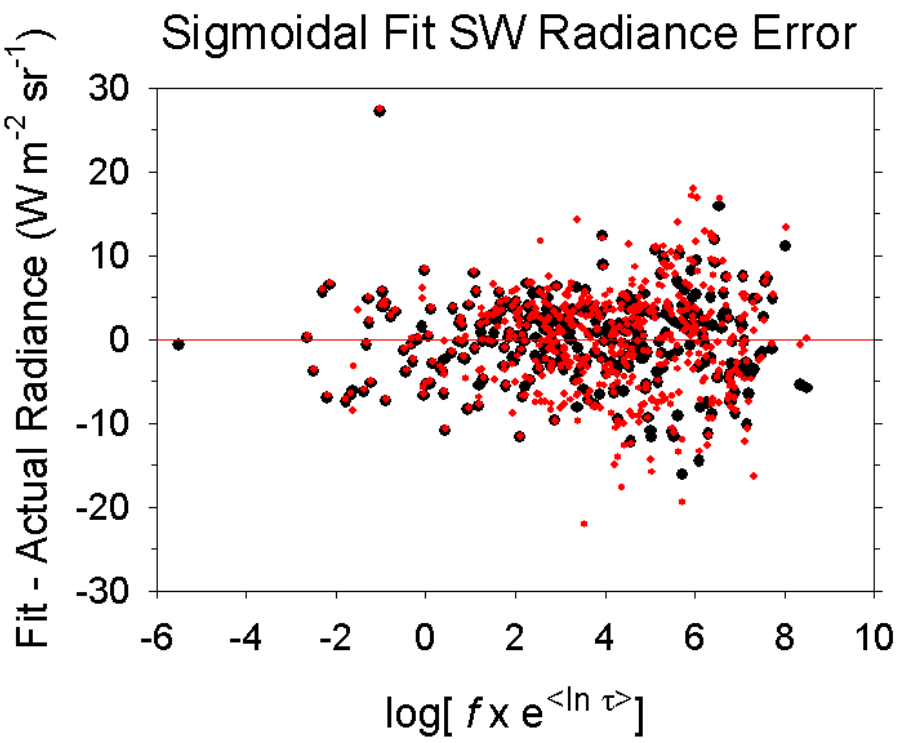
2. Longwave and Window:

- Similar to CERES/TRMM but at higher angular resolution
- Empirical ADMs over snow

Sigmoidal Function Fits to SW Radiances

(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

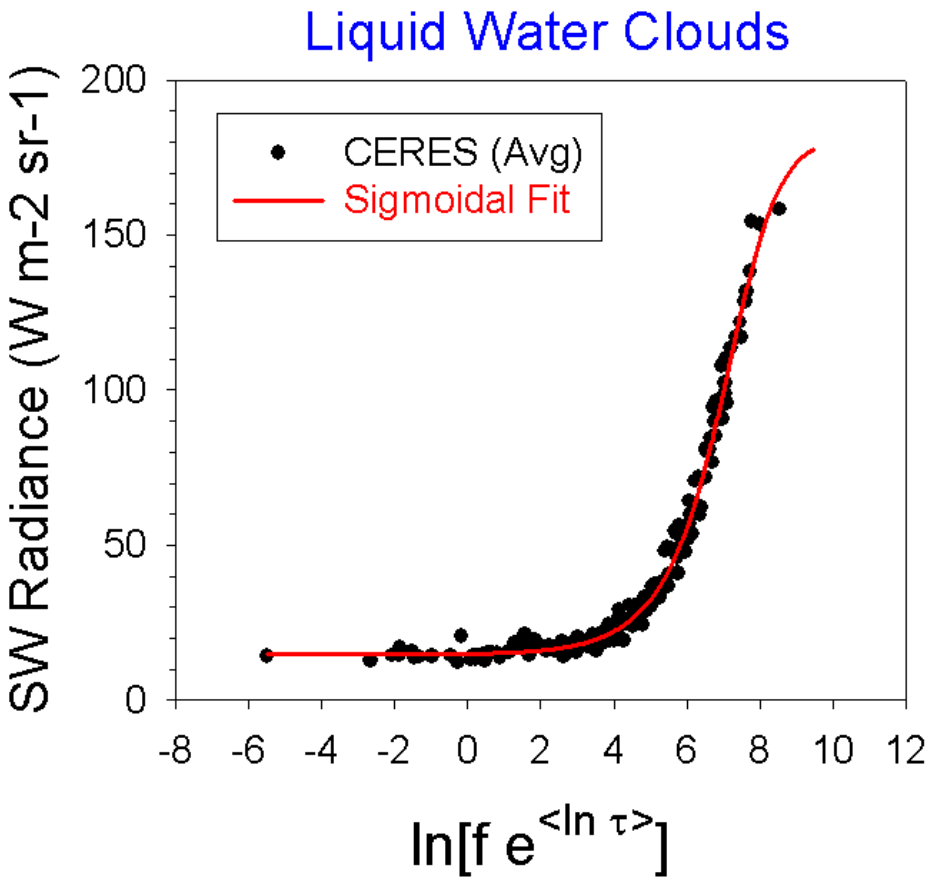
$$I = I_o + \frac{a}{\left[1 + e^{-\left(\frac{x - x_o}{b}\right)}\right]^c}$$

$$x = fe^{<\ln \tau>}$$

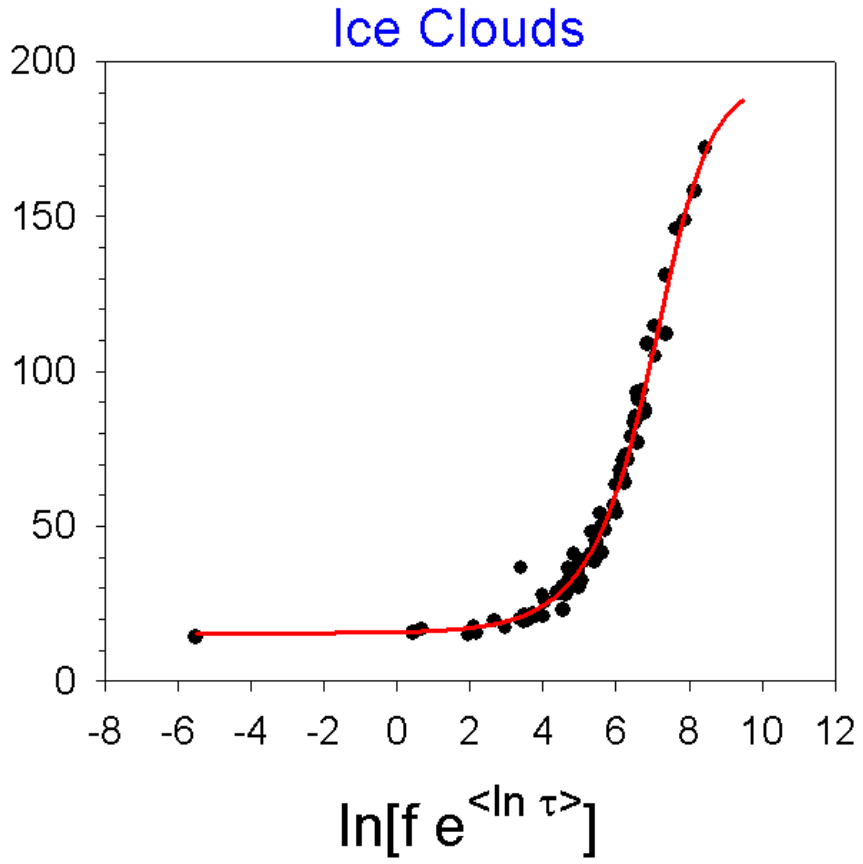
where,

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

Sigmoidal Function Fits to SW Radiances
(θ_o=48°-50°; θ=0°-2°; ϕ=0°-2°)



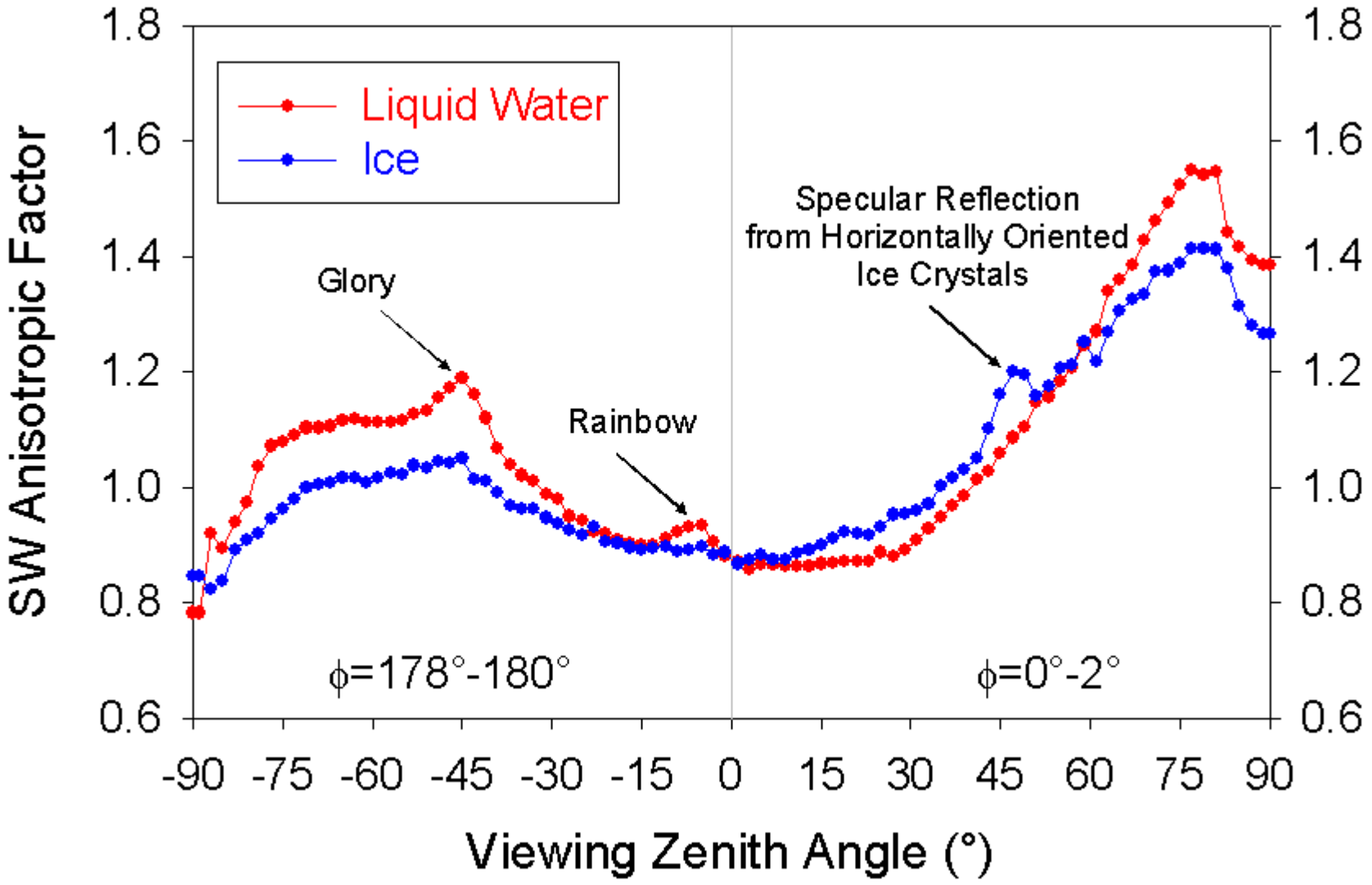
Avg Rad = 42.3 W m^{-2} sr^{-1}
Bias = 0.003 W m^{-2} sr^{-1} (0.0%)
Stdev = 3.76 W m^{-2} sr^{-1} (8.9%)



Avg Rad = 126.0 W m^{-2} sr^{-1}
Bias = 0.026 W m^{-2} sr^{-1} (0.0%)
Stdev = 4.91 W m^{-2} sr^{-1} (3.9%)

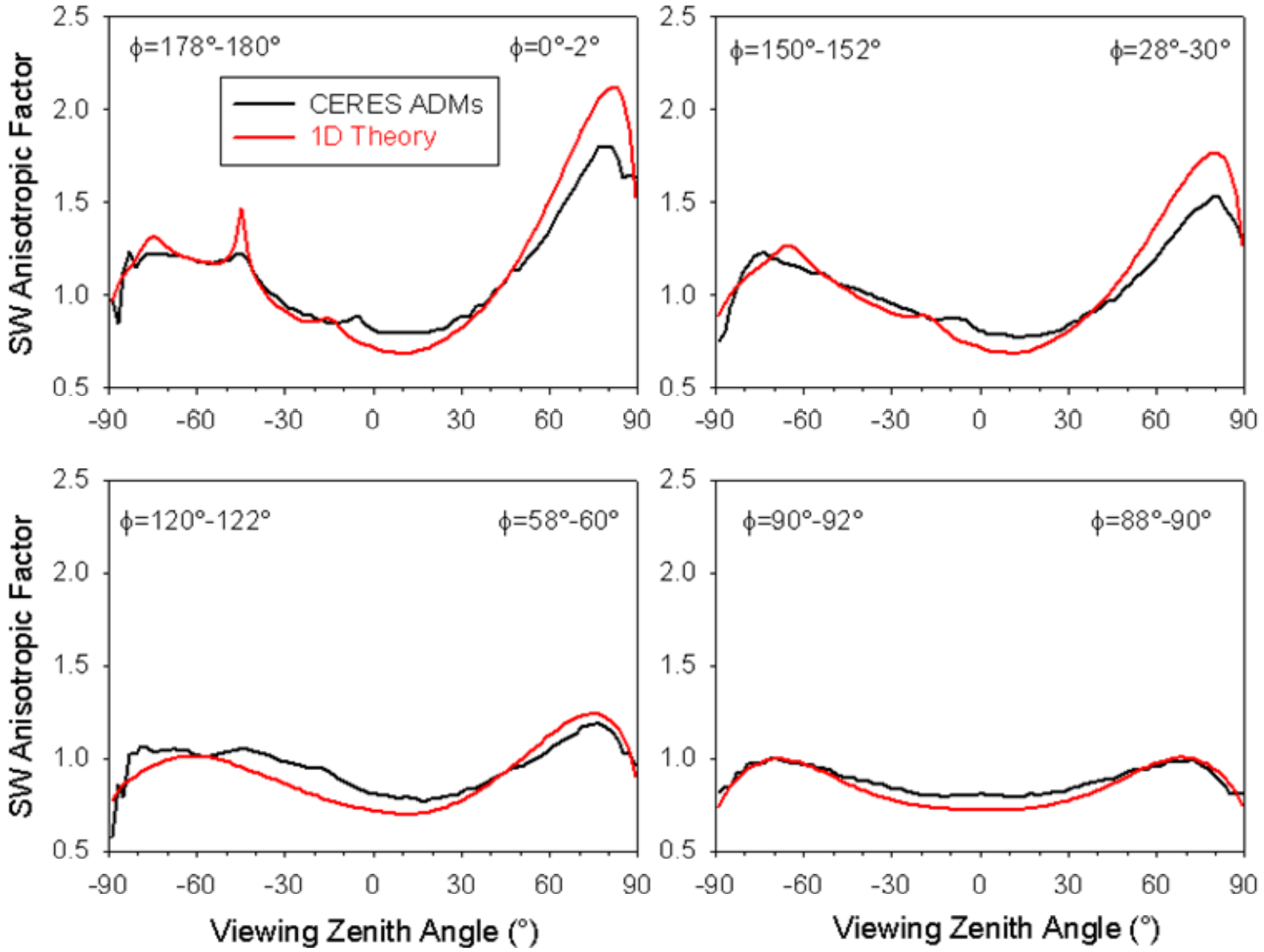
CERES/Terra ADM Anisotropic Factors in the Principal Plane

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



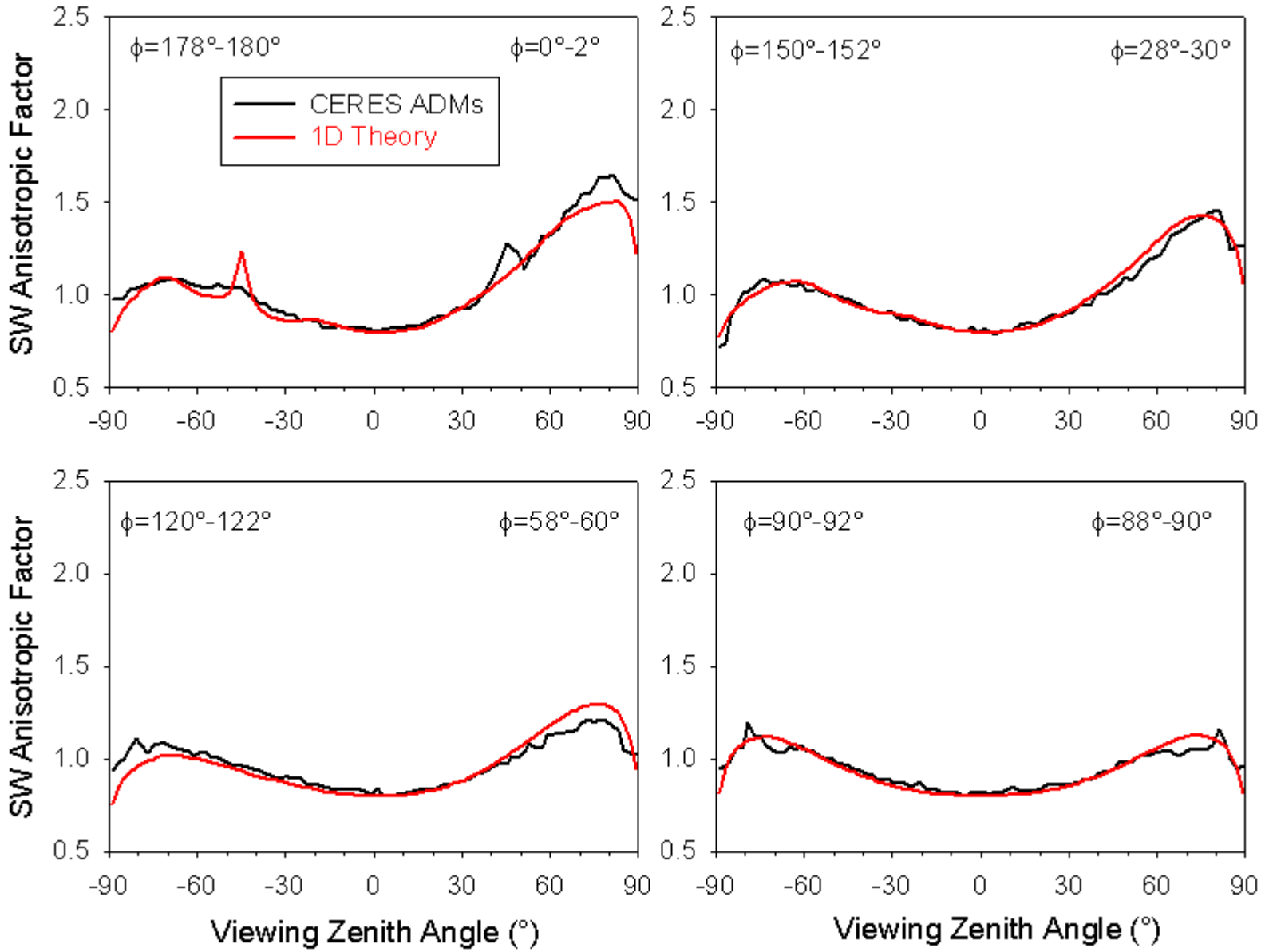
CERES/Terra ADM Anisotropic Factors

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



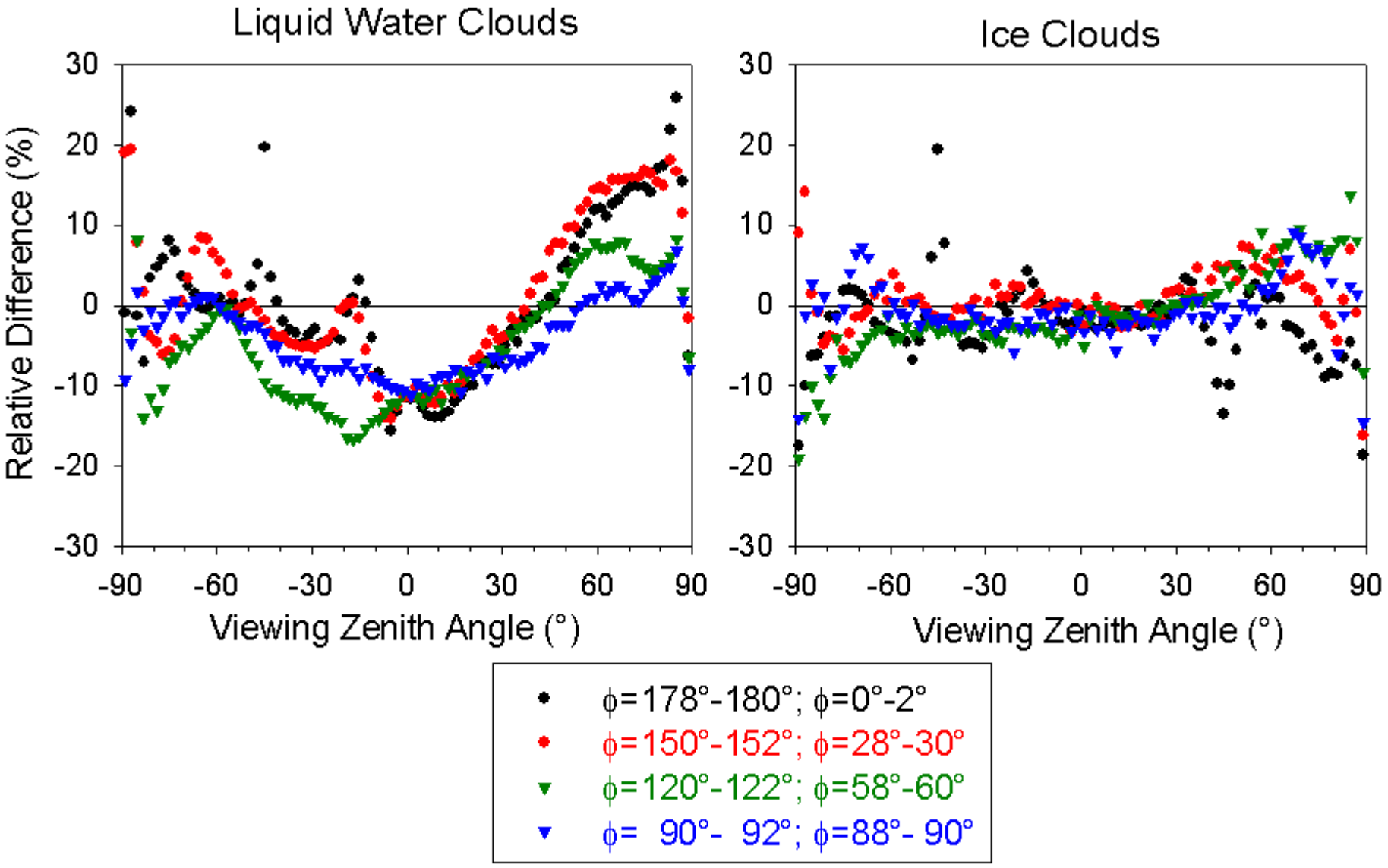
CERES/Terra ADM Anisotropic Factors

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



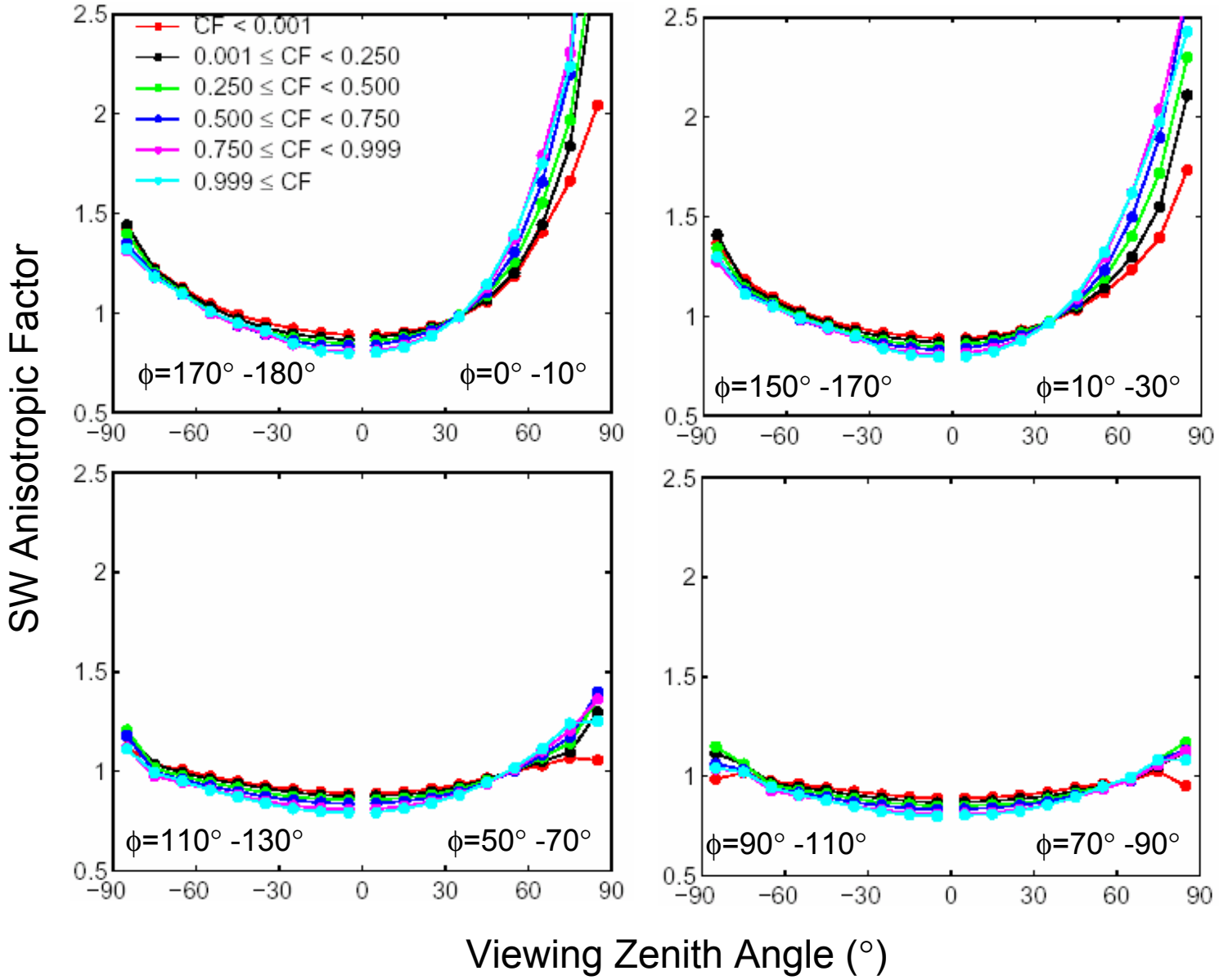
Theory vs CERES SW ADMs

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



CERES/Terra ADM Anisotropic Factors

(Permanent Snow; θ_o=70°-75°)



Summary

CERES goes well beyond ERBE:

- Coincident imager-based cloud and aerosol properties together with broadband CERES radiative fluxes.

- New CERES SSF SW fluxes show less dependence on viewing geometry than CERES ERBE-Like (≈10% for ES8; ≈1.5% SSF).

- Improved accuracy of TOA fluxes by a factor of 2.

- CERES goal for regional mean flux accuracy ($1\sigma < 1$ W m^{-2}) is attained provided full viewing zenith angle coverage < 70° is used.

Future Work

- Improve CERES/Terra and CERES/Aqua TOA flux accuracy over CERES/TRMM. Separate ADMs for each instrument.
- Empirical SW, LW and WN ADMs over snow.
- Determine flux errors by cloud type, cloud and clear-sky parameters.
- Comparisons with other instruments: MISR, GERB and POLDER.
- Merging of measurements from CERES & MODIS (Aqua) with CALIPSO, CloudSat, PARASOL.

Recent ADM Publications:

Loeb, N.G.,et al., 2002: Angular distribution models for top-of-atmosphere radiative flux estimation from the Clouds and the Earth's Radiant Energy System instrument on the Tropical Rainfall Measuring Mission Satellite. Part II: Validation, *J. Appl. Meteor*. (submitted).

Loeb, N.G.,et al., 2002: Angular distribution models for top-of-atmosphere radiative flux estimation from the Clouds and the Earth's Radiant Energy System instrument on the Tropical Rainfall Measuring Mission Satellite. Part I: Methodology, *J. Appl. Meteor*., **42**, 240-265.

Loeb, N.G., S. Kato, and B.A. Wielicki, 2002: Defining top-of-atmosphere flux reference level for Earth Radiation Budget studies, *J. Climate*, **15**, 3301-3309.

Kato, S., and N.G. Loeb, 2002: Twilight irradiance reflected by the Earth estimated from Clouds and the Earth's Radiant Energy System (CERES) measurements, *J. Climate* (in press).

Loeb, N.G., F. Parol, J.-C. Buriez, and C. Vanbauce, 2000: Top-of-atmosphere albedo estimation from angular distribution models using scene identification from satellite cloud property retrievals. *J. Climate*, **13**,1269-1285.

Loeb, N.G., P. O'R. Hinton, and R.N. Green, 1999: Top-of-atmosphere albedo estimation from angular distribution models: a comparison between two approaches. *J. Geophys. Res*., **104**, 31,255-31,260.