Development of New CERES/Terra Angular Distribution Models

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Outline

- TOA Flux Group Activities
- Terra SW ADM Development
- New Approach for SW ADMs in Cloudy Conditions
- SW ADMs Over Snow
- Clear and Overcast LW ADMs
- Regional Instantaneous TOA Flux Consistency Checks

TOA Flux Group Activities

May 2002 – September 2002

- ADM Publications:

i) Paper on TOA flux reference level in press (*J. Climate*)

ii) ADM paper (Part I) describing CERES/TRMM SW, LW & WN ADMs accepted (*J. Appl. Meteor.*).

iii) Parts II & III summarizing TRMM ADM validation results are in preparation.

iv) Paper on use of neural networks for TOA flux estimation (Loukachine) in preparation.

September 2002 – June 2003

- Development and validation of Terra ADMs based on 2 years of CERES/Terra RAP measurements.
- So far, only 4 months…

Terra SW 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.
- Snow and sea-ice.
- Use new MODIS products (e.g. aerosol properties)?
- Neural network scheme to improve TOA flux estimates for footprints with excessive "no retrievals".
- Validation: Improve instantaneous TOA flux consistency tests (alongtrack).
- Comparisons with MISR?

Proposed Terra SW ADMs – Clear Scenes

Clear Ocean:

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

Clear Land:

Stratify by IGBP type + vegetation index

=> Is there any change in anisotropy? Can we use MODIS aerosol product for smoke and dust ADMs?

Clear Desert:

Same strategy as CERES/TRMM but higher angular resolution (separate ADMs for dark and bright desert regions).

Clear Snow:

Stratify by permanent snow, fresh snow over land and sea ice. Use NDSI as additional classifier.

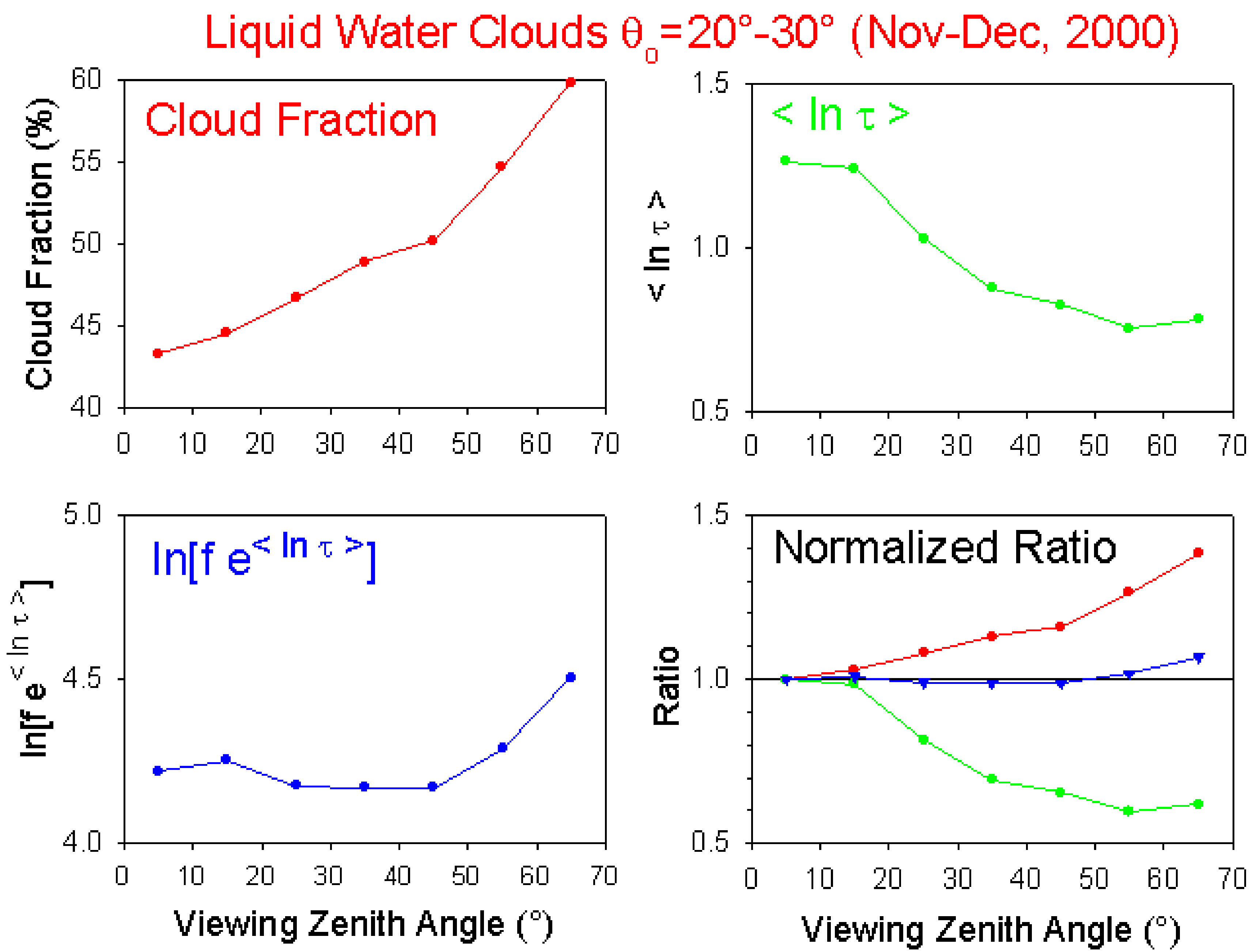
Terra SW ADMs – Cloudy Scenes

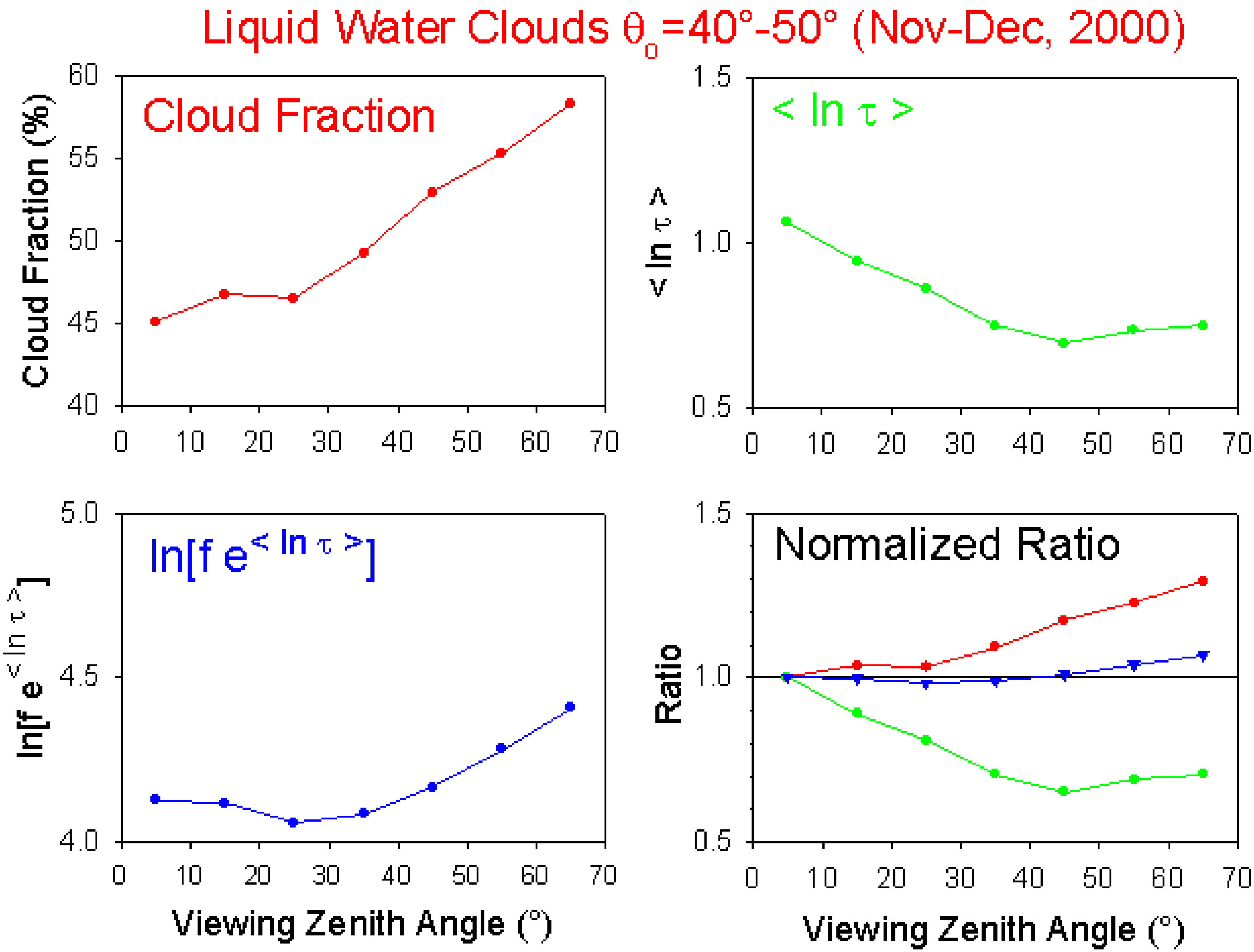
Clouds over Ocean:
"Continuous" ADMs using sigmoidal fit approach for 4 cloud phase categories.

Clouds over Land and Desert:
Similar approach as over ocean but with 2 phase categories.

Clouds over Snow:
Stratify by phase, cloud fraction and cloud optical depth.

Towards an <u>Infinite</u> Number of Scene Types for SW ADMs in Cloudy Conditions

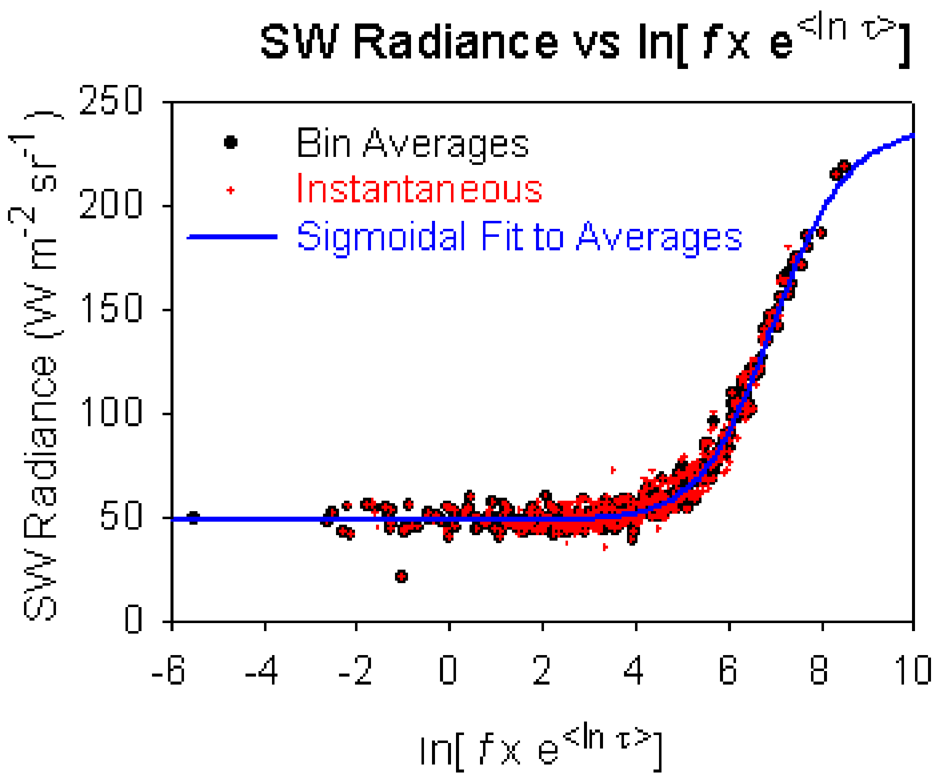

Liquid Water Clouds θ0=20°-30° (Nov-Dec, 2000)
Cloud Fraction
Cloud Fraction (%)
< ln τ >
< ln τ >
ln[f e< ln τ >]
ln[f e< ln τ >]
Normalized Ratio
Ratio
Viewing Zenith Angle (°)
Viewing Zenith Angle (°)

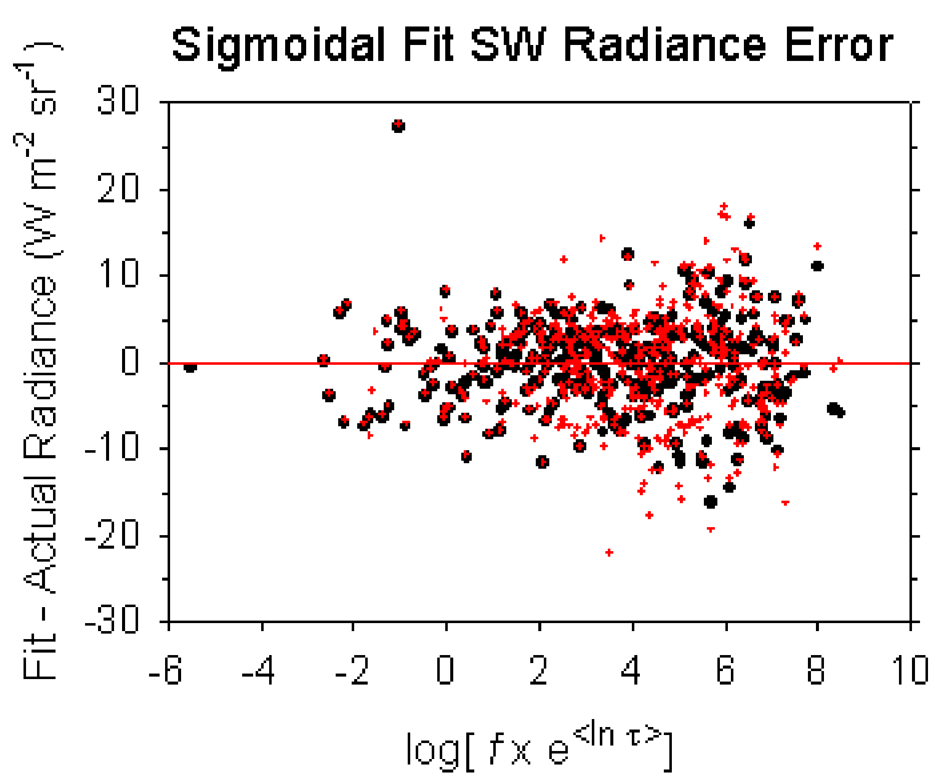


Liquid Water Clouds θ0=40°-50° (Nov-Dec, 2000)
Cloud Fraction
Cloud Fraction (%)
60
55
50
45
40
0 10 20 30 40 50 60 70
< ln τ >
< ln τ >
1.5
1.0
0.5
0 10 20 30 40 50 60 70
ln[f e^< ln τ >]
ln[f e^< ln τ >]
5.0
4.5
4.0
0 10 20 30 40 50 60 70
Viewing Zenith Angle (°)
Normalized Ratio
Ratio
1.5
1.0
0.5
0 10 20 30 40 50 60 70
Viewing Zenith Angle (°)

Uncertainties in Sigmoidal SW Radiance Fits

(Liquid Water Clouds; θ_0=34°-36°; θ=50°-52°; ϕ=6°-8°; TRMM+Terra RAPS+Alongtrack)



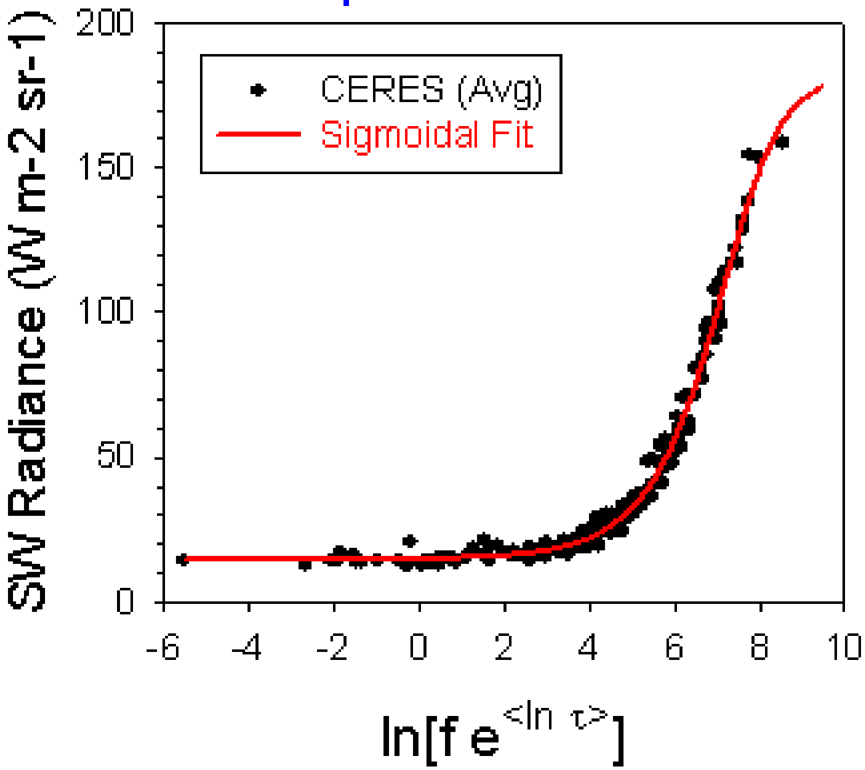


Avg Rad = 70.5 $W\,m^{-2}\,sr^{-1}$
Bias = 0.038 $W\,m^{-2}\,sr^{-1}$ (0.05%)
Stdev = 5.26 $W\,m^{-2}\,sr^{-1}$ (7.5%)

SW Radiance vs $\ln[f\, e^{\langle \ln \tau \rangle}]$

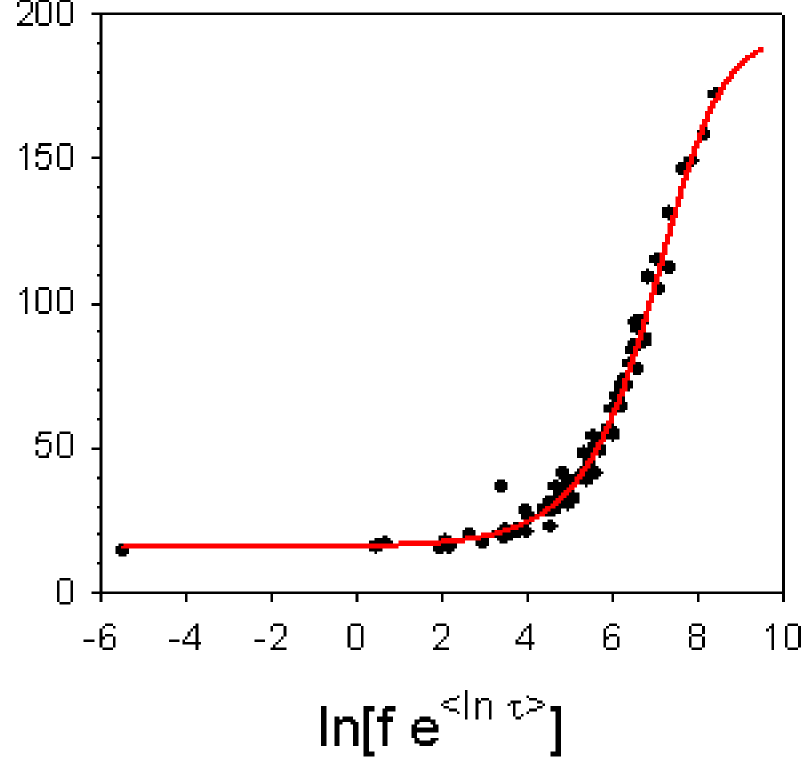
$(\theta_o = 48°\text{-}50°;\ \theta = 0°\text{-}2°;\ \phi = 0°\text{-}2°)$

Liquid Water Clouds



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%)

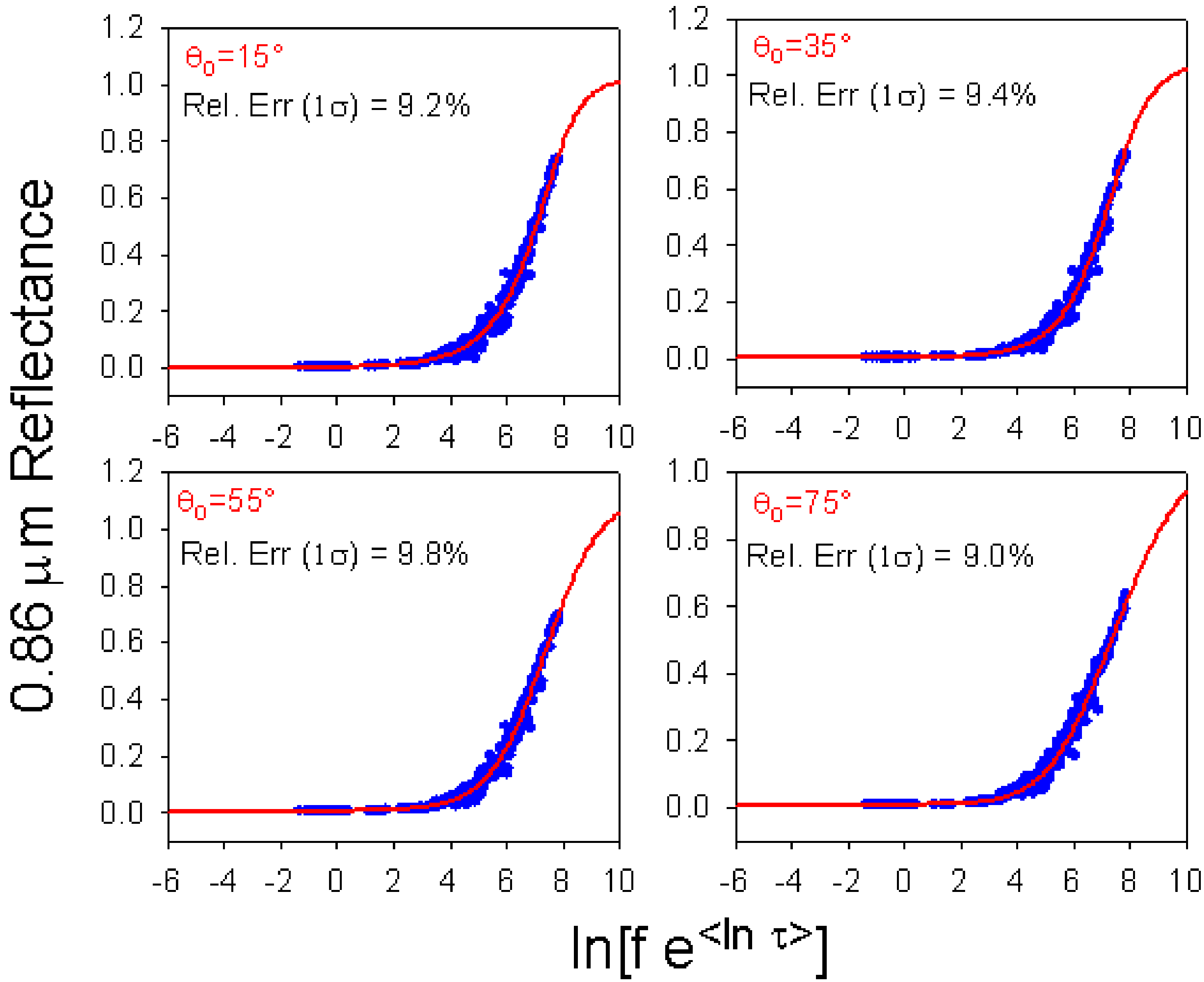
Ice Clouds



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%)

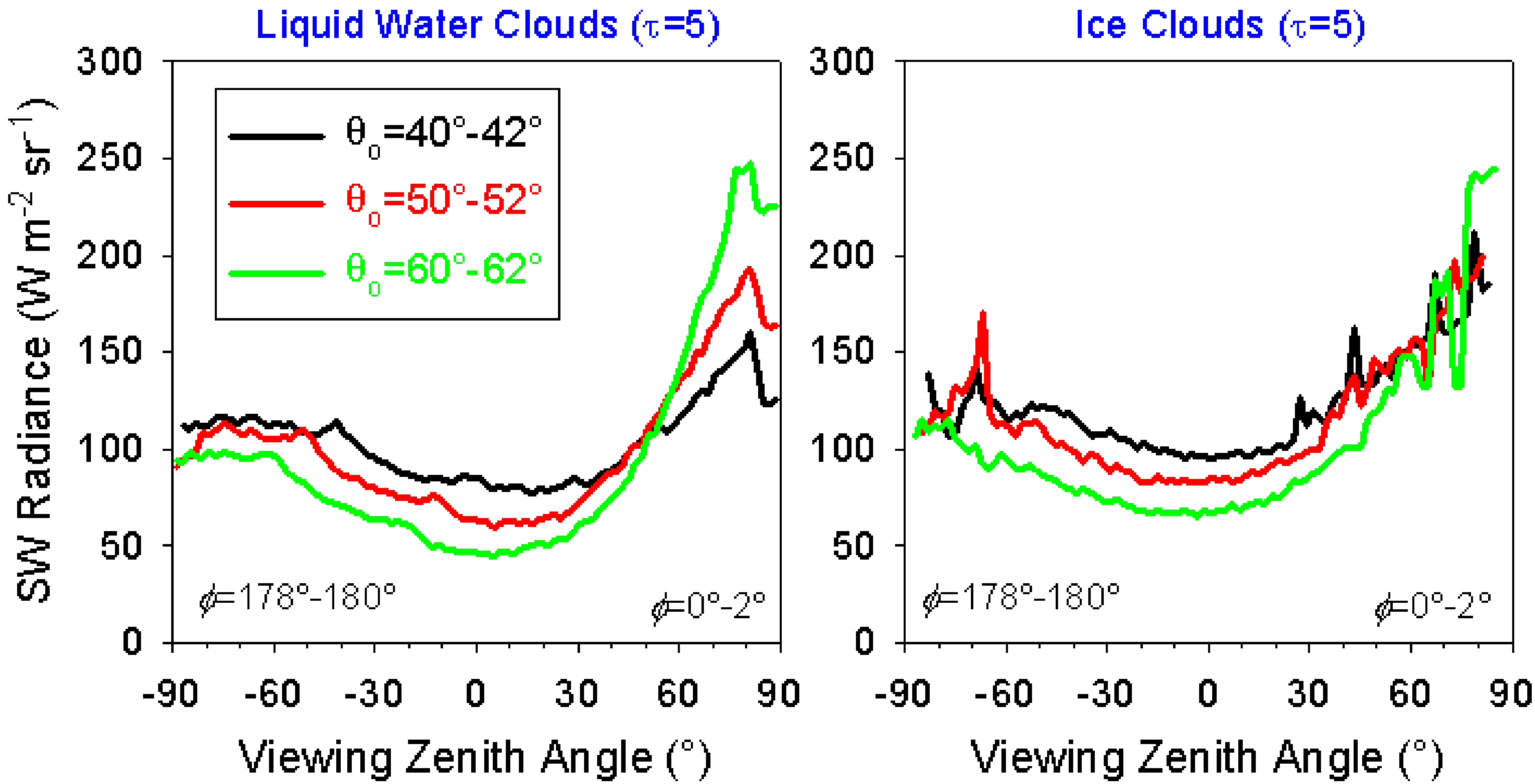
2D SHDOM Results Applied to Landsat Boundary Layer Clouds

(Nadir Viewing Zenith Angle)



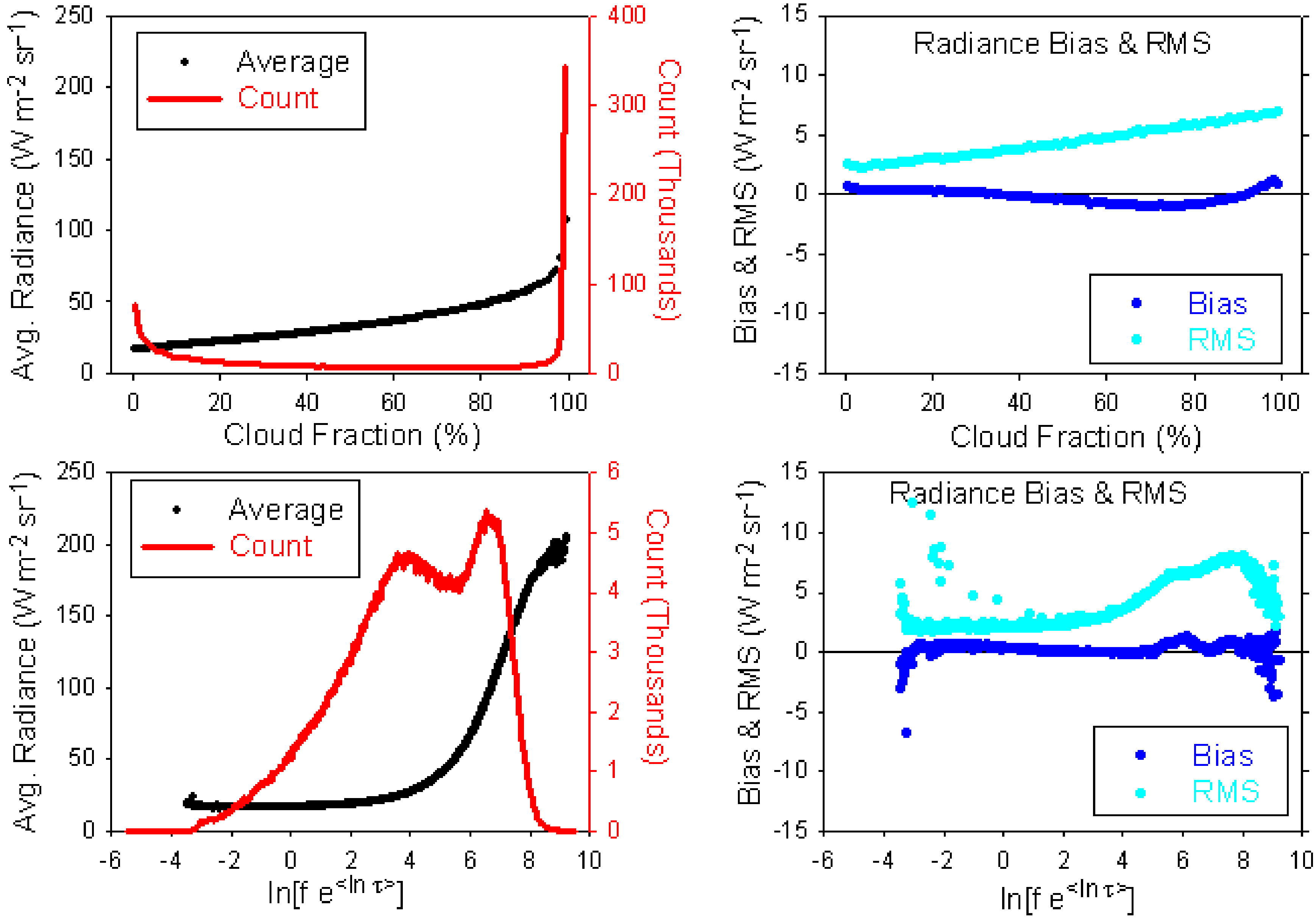
CERES SW Radiances vs Viewing Zenith Angle

(Principal Plane; 4 Months Terra over Ocean)



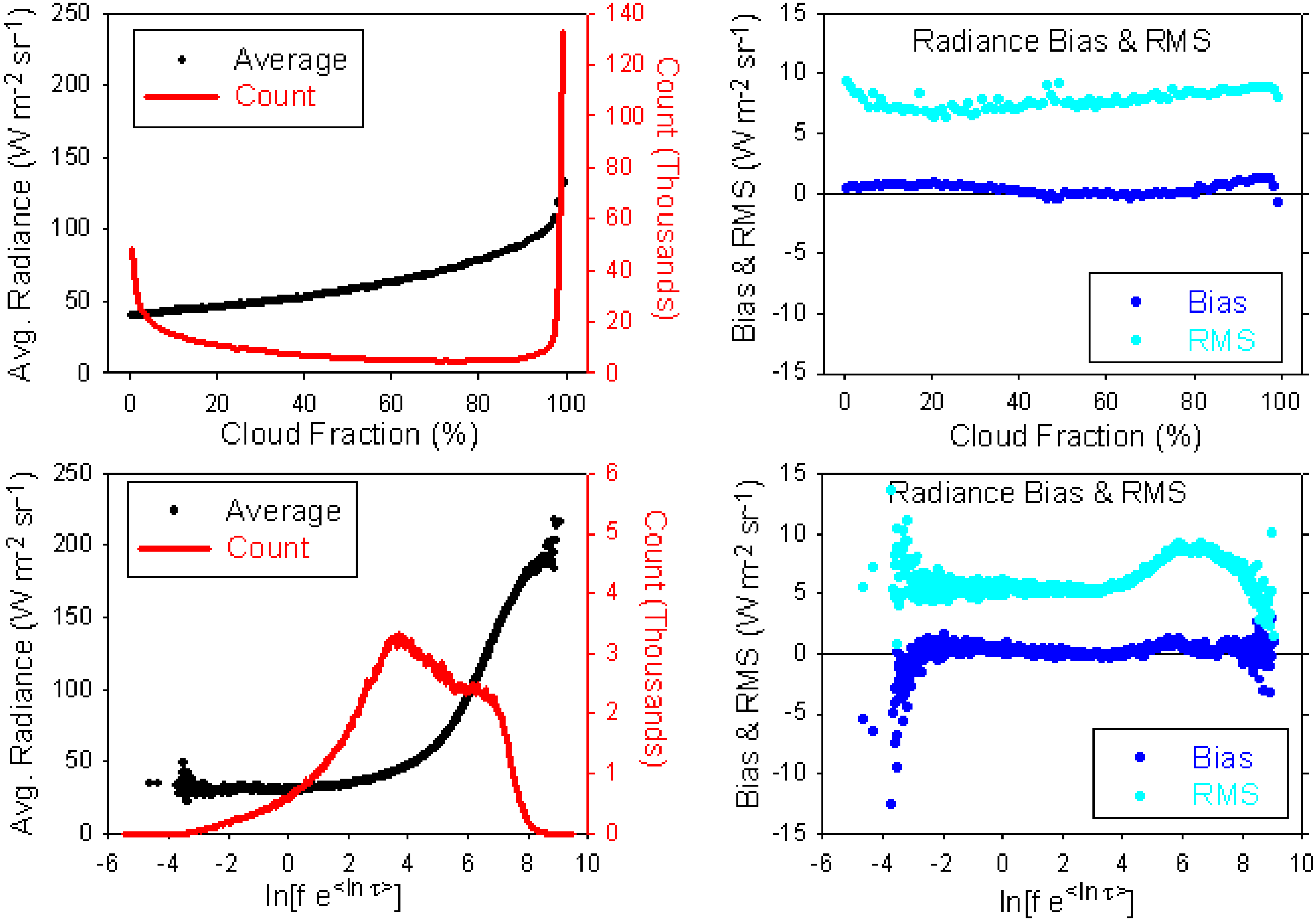
Errors in SW Radiance Sigmoidal Fits

(Liquid Water Clouds Over Ocean; θ_o=40°-50°; θ=0°-20°



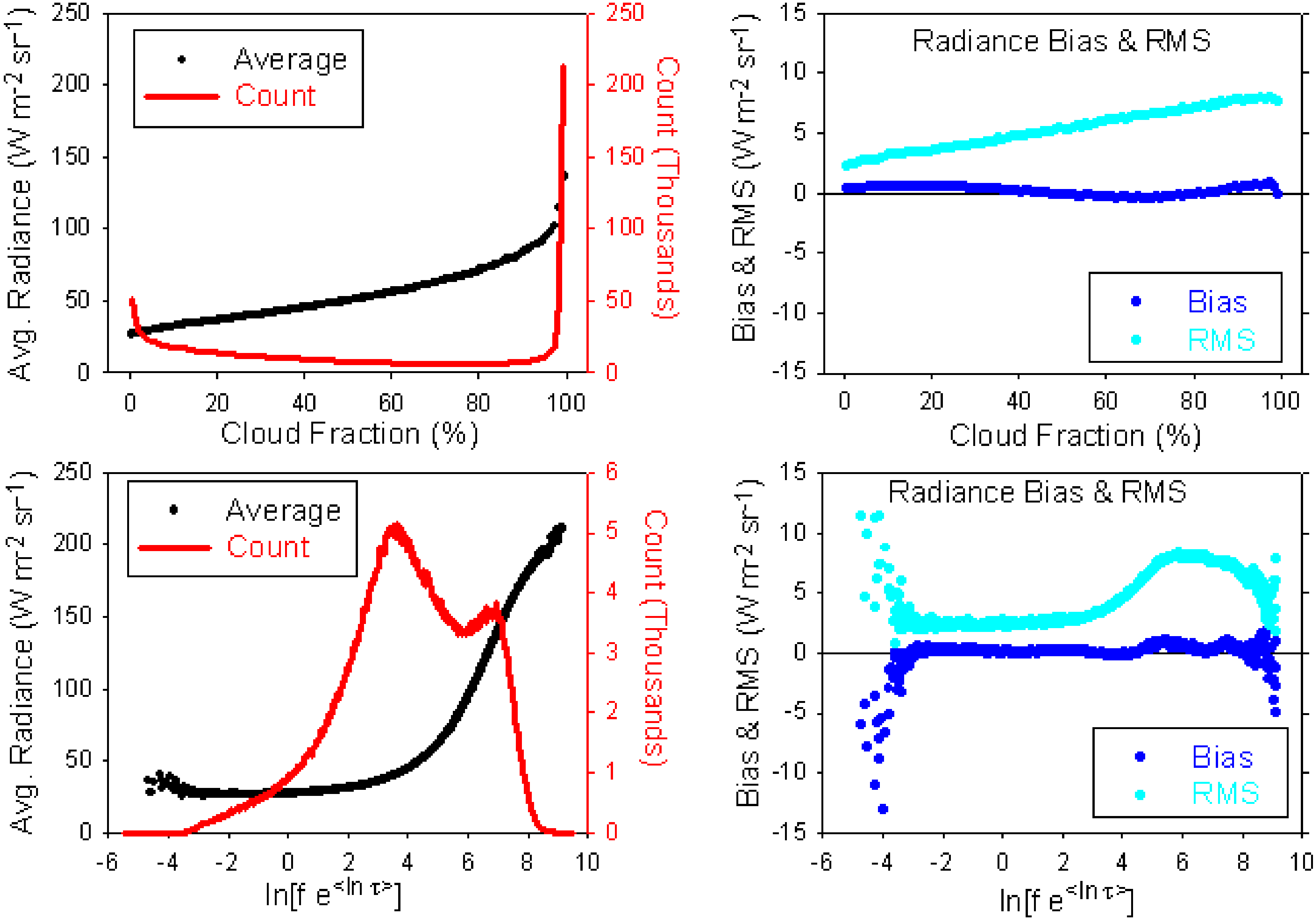
Errors in SW Radiance Sigmoidal Fits

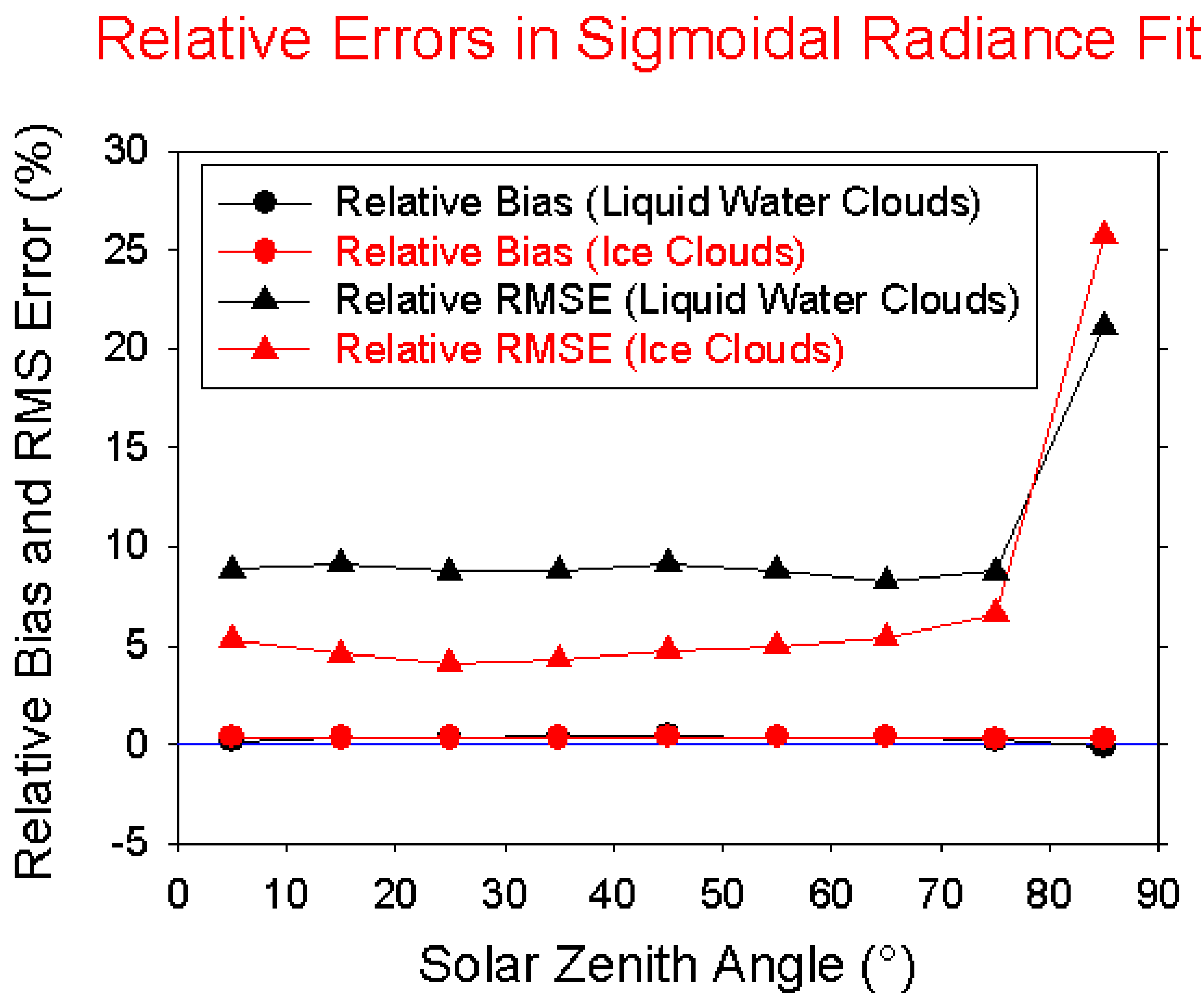
(Liquid Water Clouds Over Ocean; θ_0=40°-50°; θ > 45°; ϕ < 60°)



Errors in SW Radiance Sigmoidal Fits

(Liquid Water Clouds Over Ocean; θ_0=40°-50°; θ > 45°; ϕ > 120°)

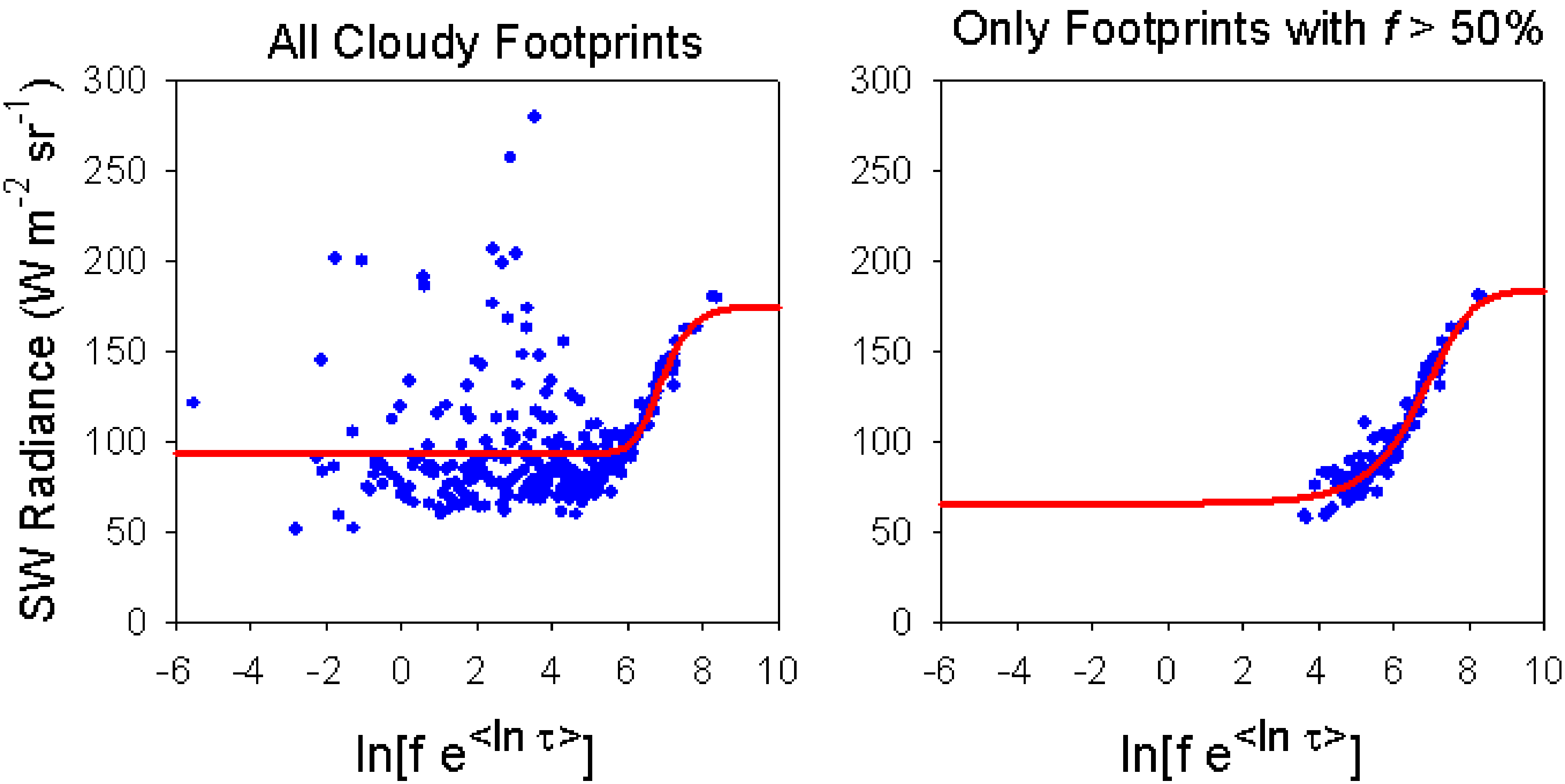




Relative Errors in Sigmoidal Radiance Fit
Relative Bias (Liquid Water Clouds)
Relative Bias (Ice Clouds)
Relative RMSE (Liquid Water Clouds)
Relative RMSE (Ice Clouds)
Relative Bias and RMS Error (%)
30
25
20
15
10
5
0
-5
0
10
20
30
40
50
60
70
80
90
Solar Zenith Angle (°)

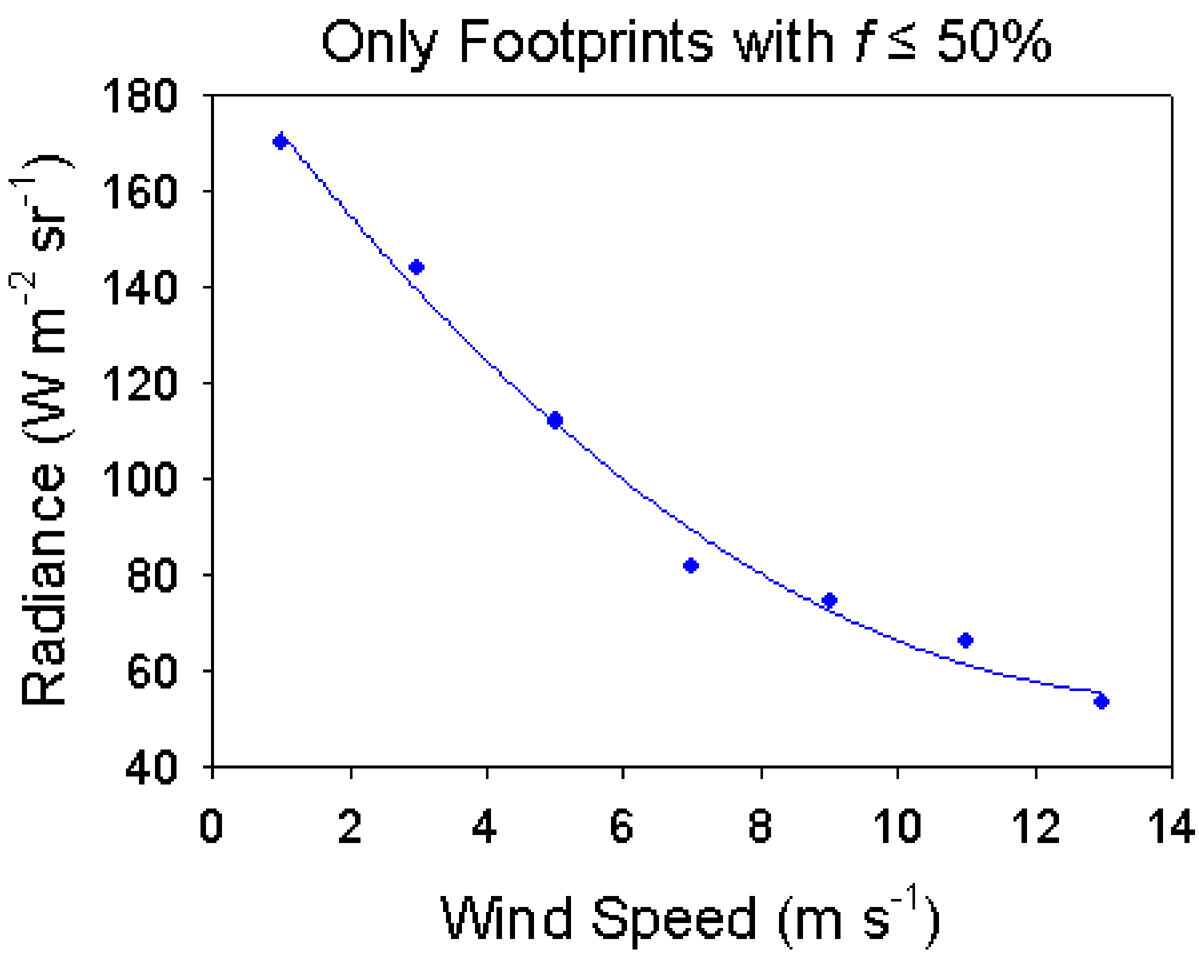
Sigmoidal Fit in Sunglint Region

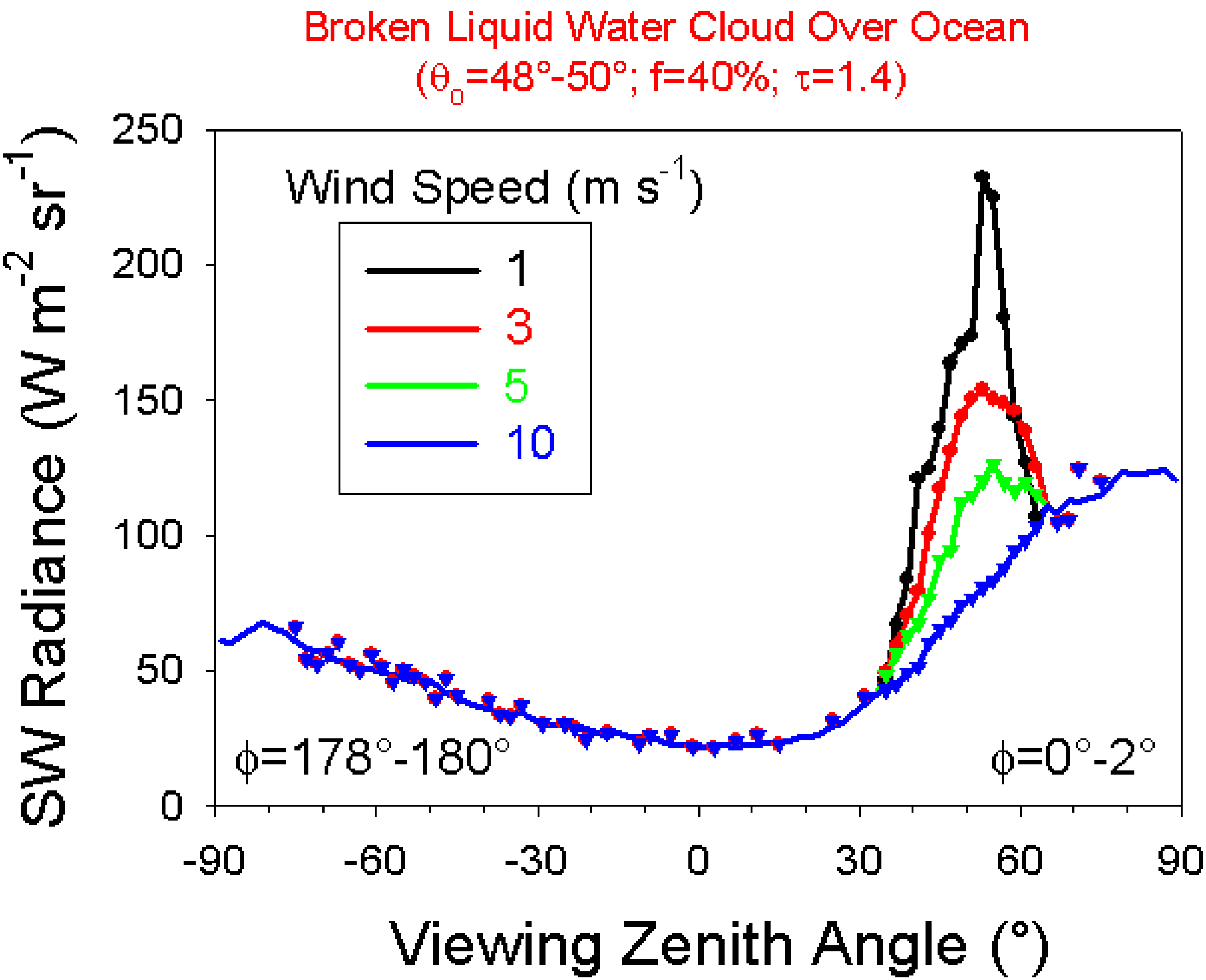
(θ_o=48°-50°; θ=48°-50°; ϕ=0°-2°)



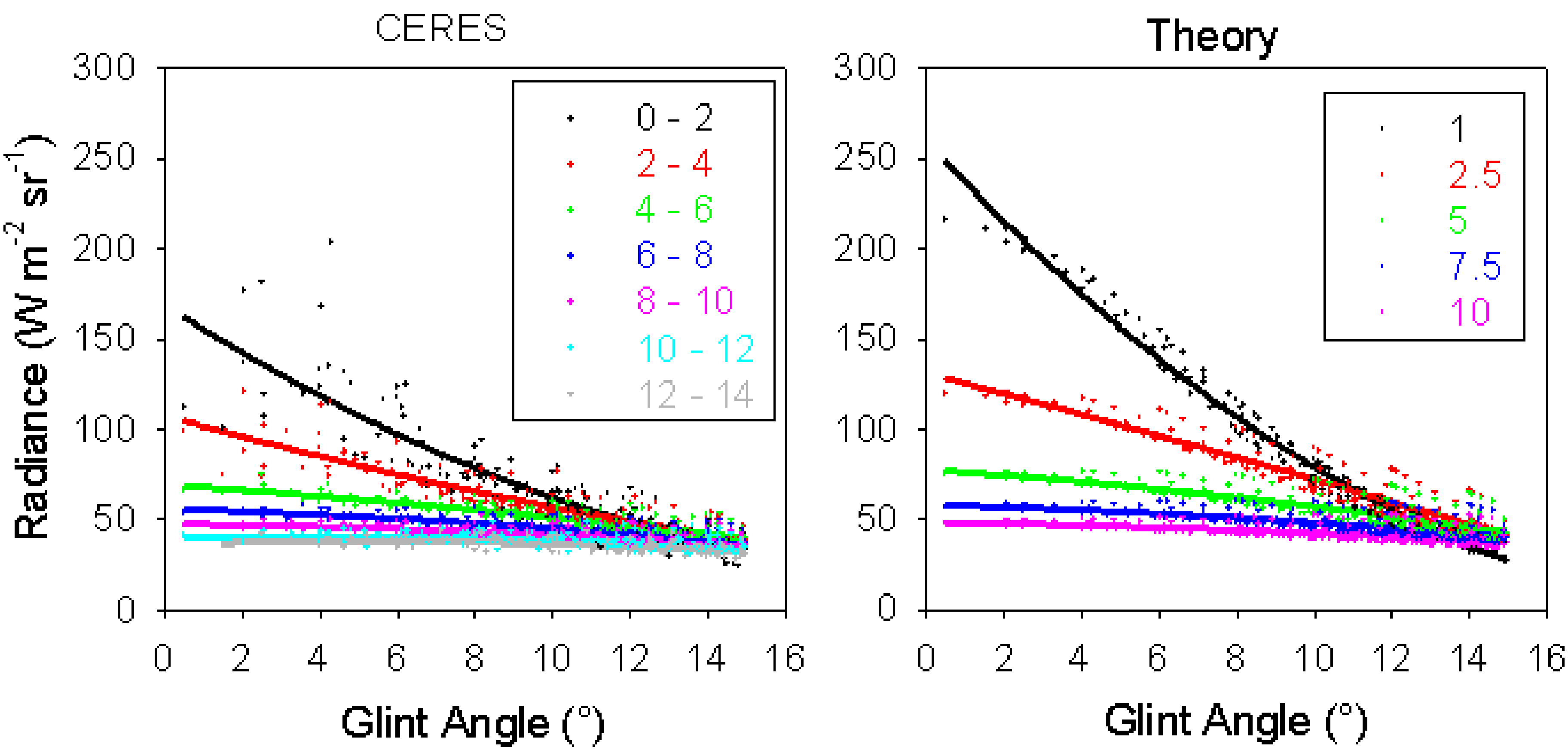
Sigmoidal Fit in Sunglint Region

(θ_o=48°-50°; θ=48°-50°; ϕ=0°-2°)

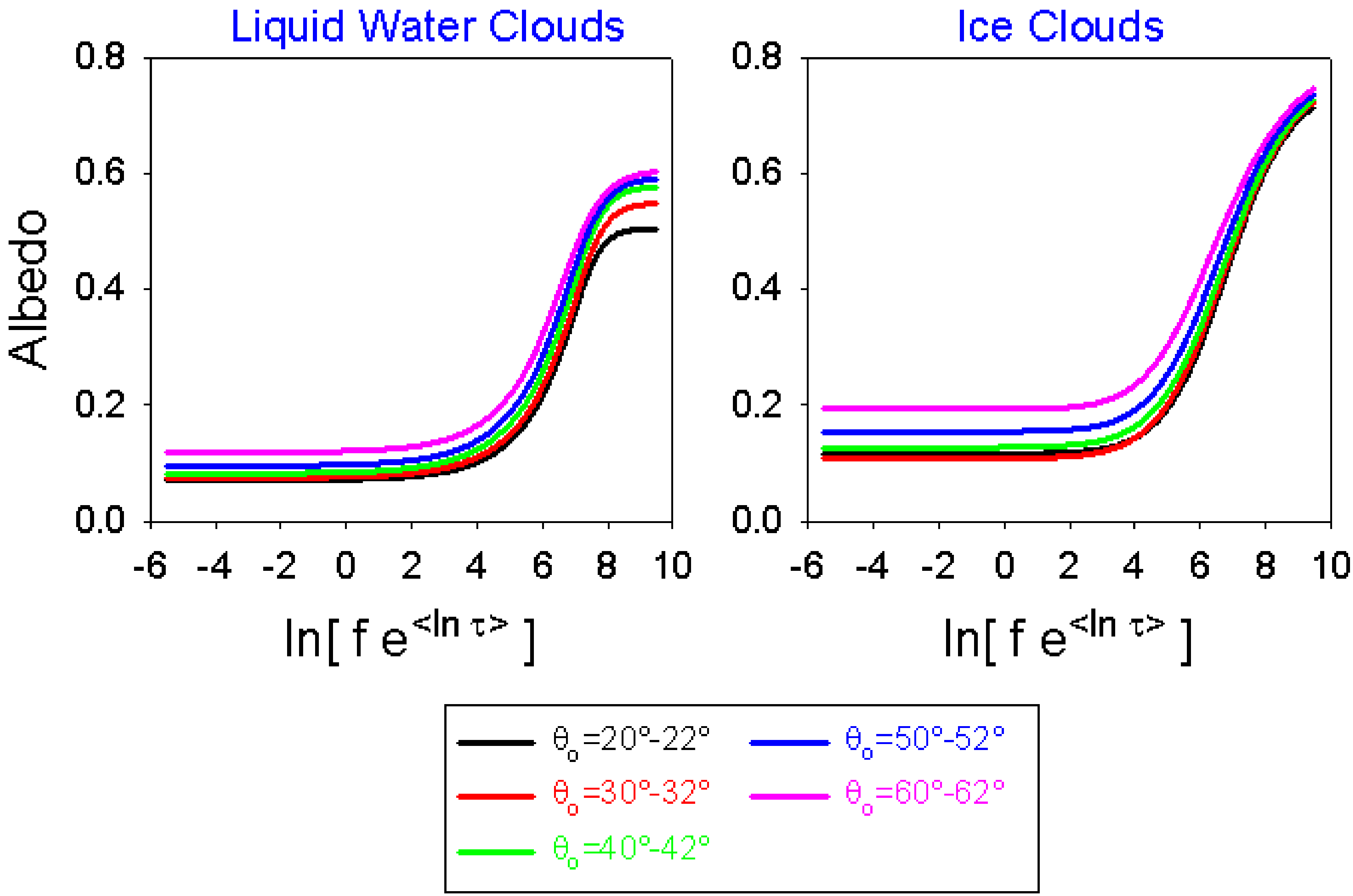



Broken Liquid Water Cloud Over Ocean
(θ0=48°-50°; f=40%; τ=1.4)
Wind Speed (m s-1)
1
3
5
10
φ=178°-180°
φ=0°-2°
SW Radiance (W m-2 sr-1)
250
200
150
100
50
0
-90
-60
-30
0
30
60
90
Viewing Zenith Angle (°)

SW Radiance Dependence on Glint Angle and Wind Speed
(Clear Ocean; θ_0=30°-32°)

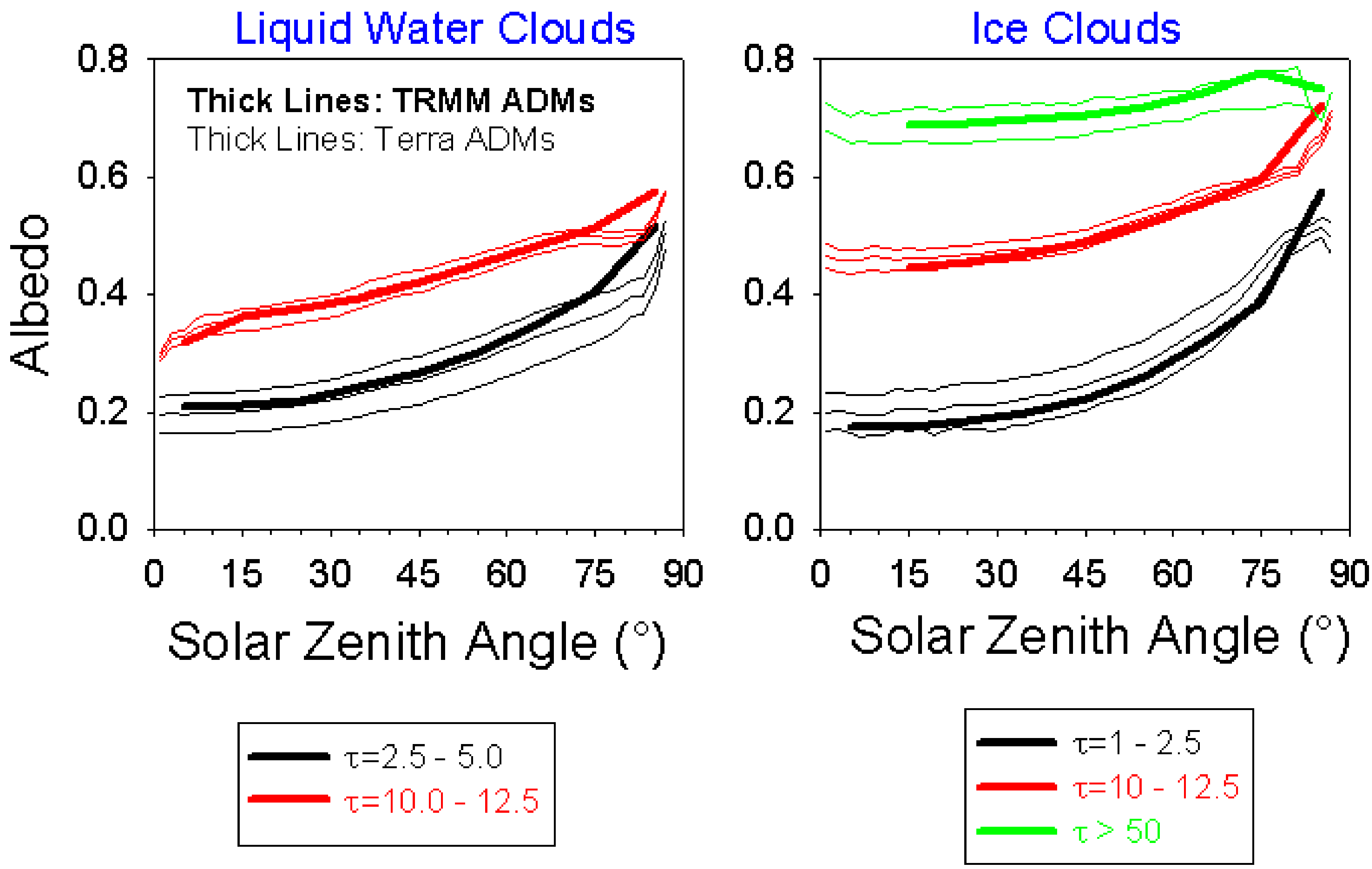


Albedo vs ln[f $e^{<\ln \tau>}$]

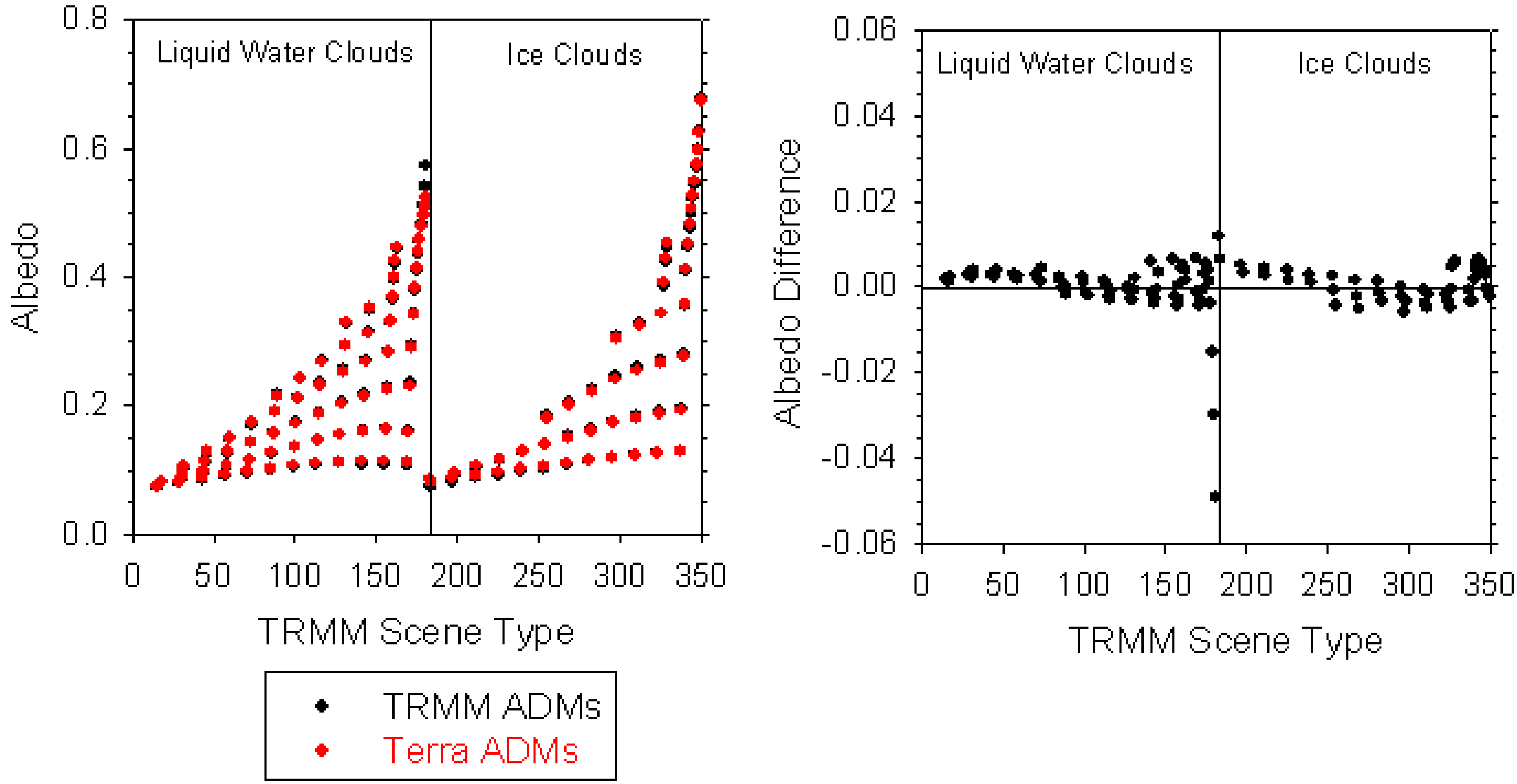


Albedo vs Solar Zenith Angle

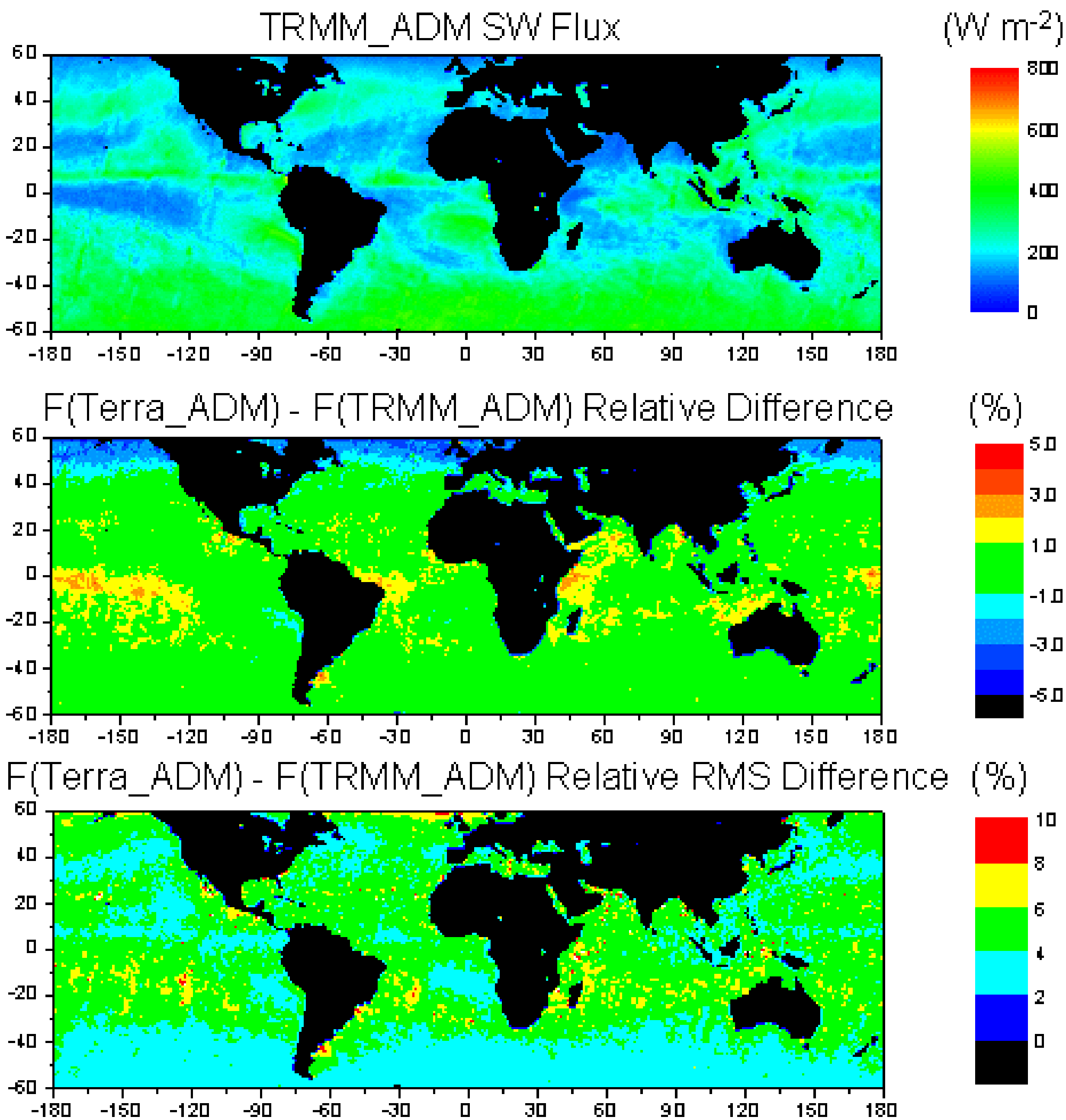
(60°S-60°N; Ocean; TRMM RAP+Terra Nov-Dec 2000+Apr-May 2001)



Albedos Over Ocean Based on CERES TRMM ADMs & Terra ADMs
Solar Zenith =20°-30°



SW Flux Comparison: TRMM vs Terra ADMs (Nov-Dec, 2000)



SW ADMs over Snow

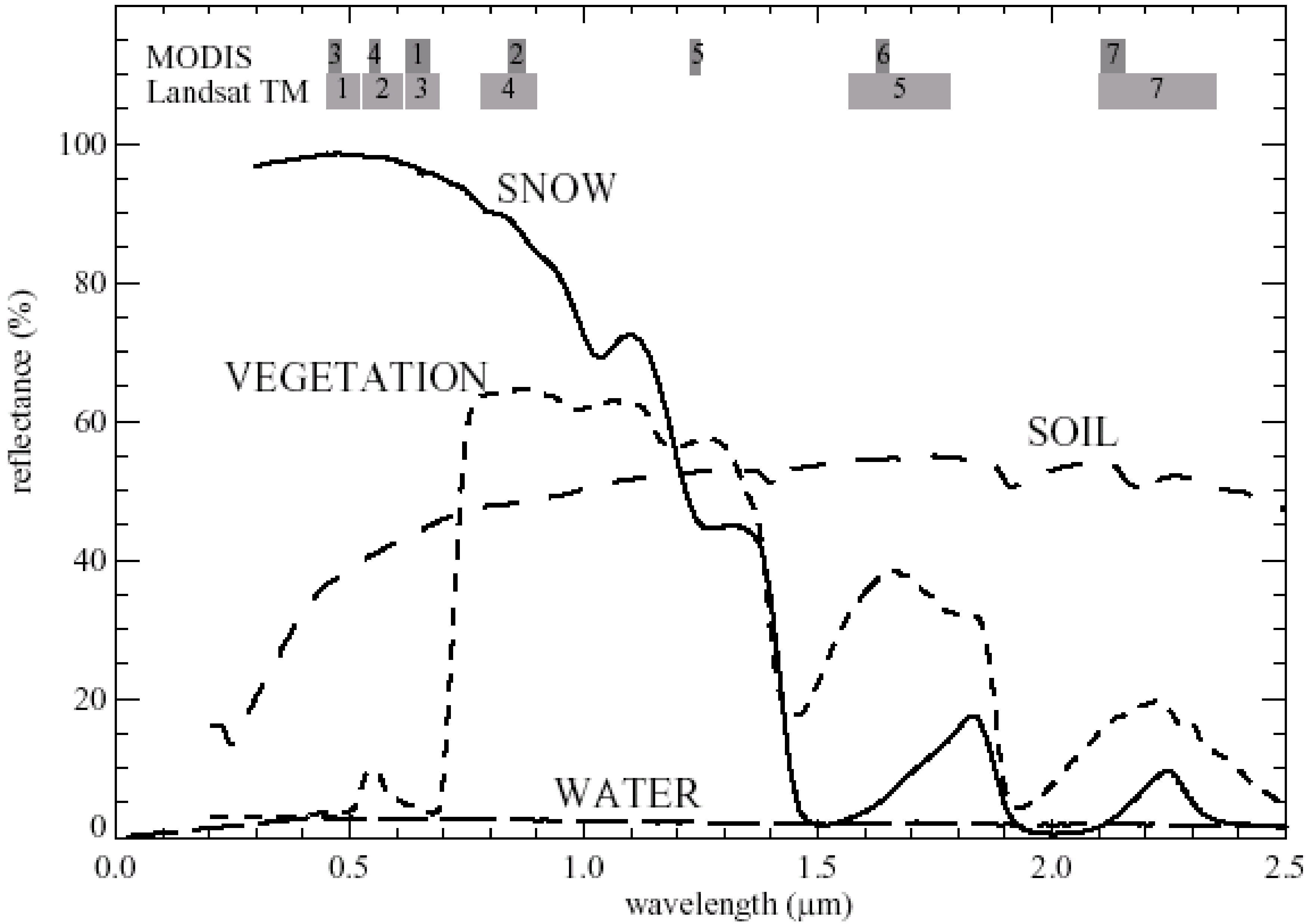
SW Radiance Anisotropy Over Snow

Stratify cloud-free scenes over snow by MODIS-derived Normalized Difference Snow Index (NDSI):

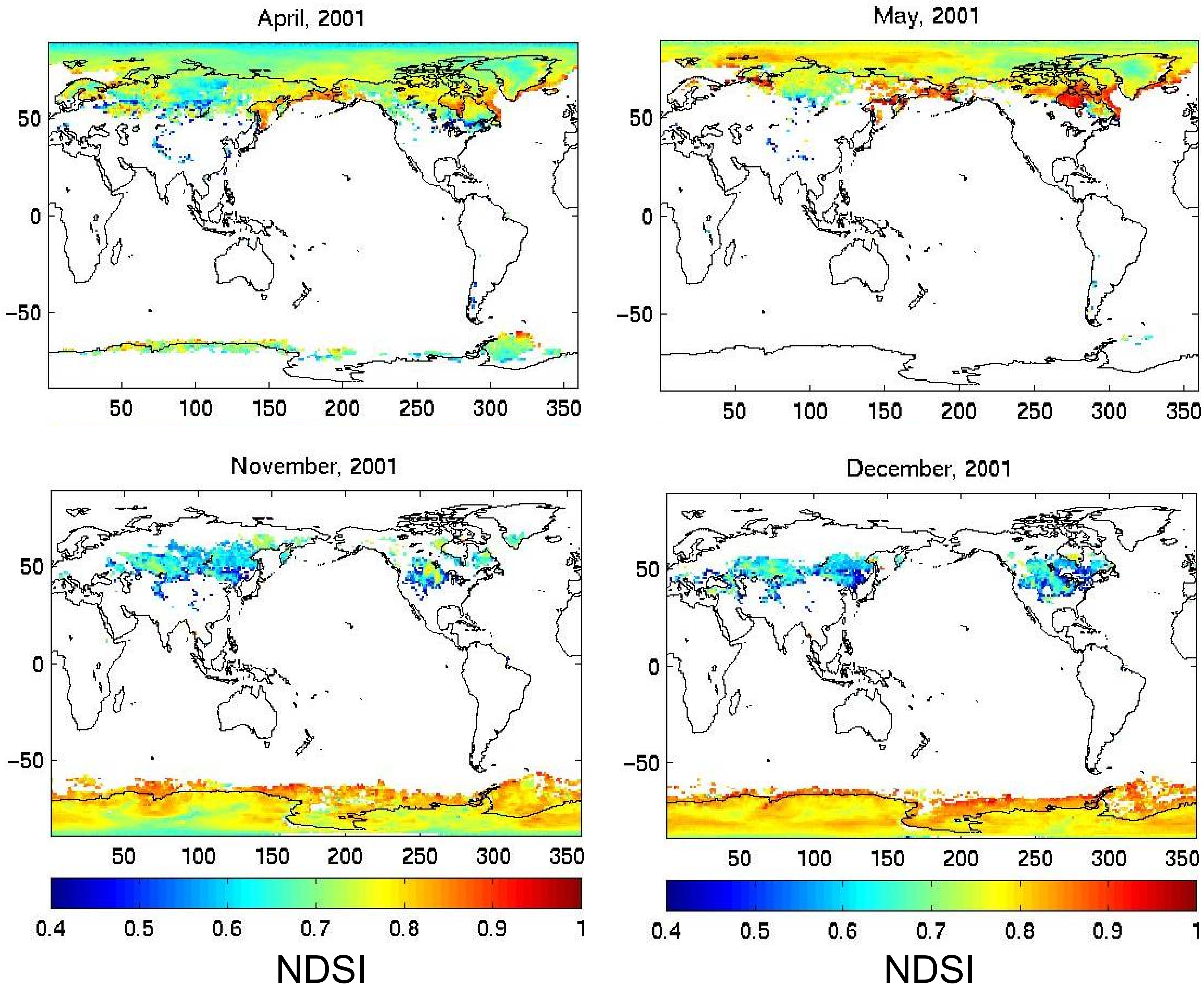
$$NDSI = \frac{r(0.645)\text{-r}(1.64)}{r(0.645)\text{+r}(1.64)}$$

$r(0.645)$=MODIS reflectance from 0.645 μm channel.

$r(1.64)$ =MODIS reflectance from 1.64 μm channel.

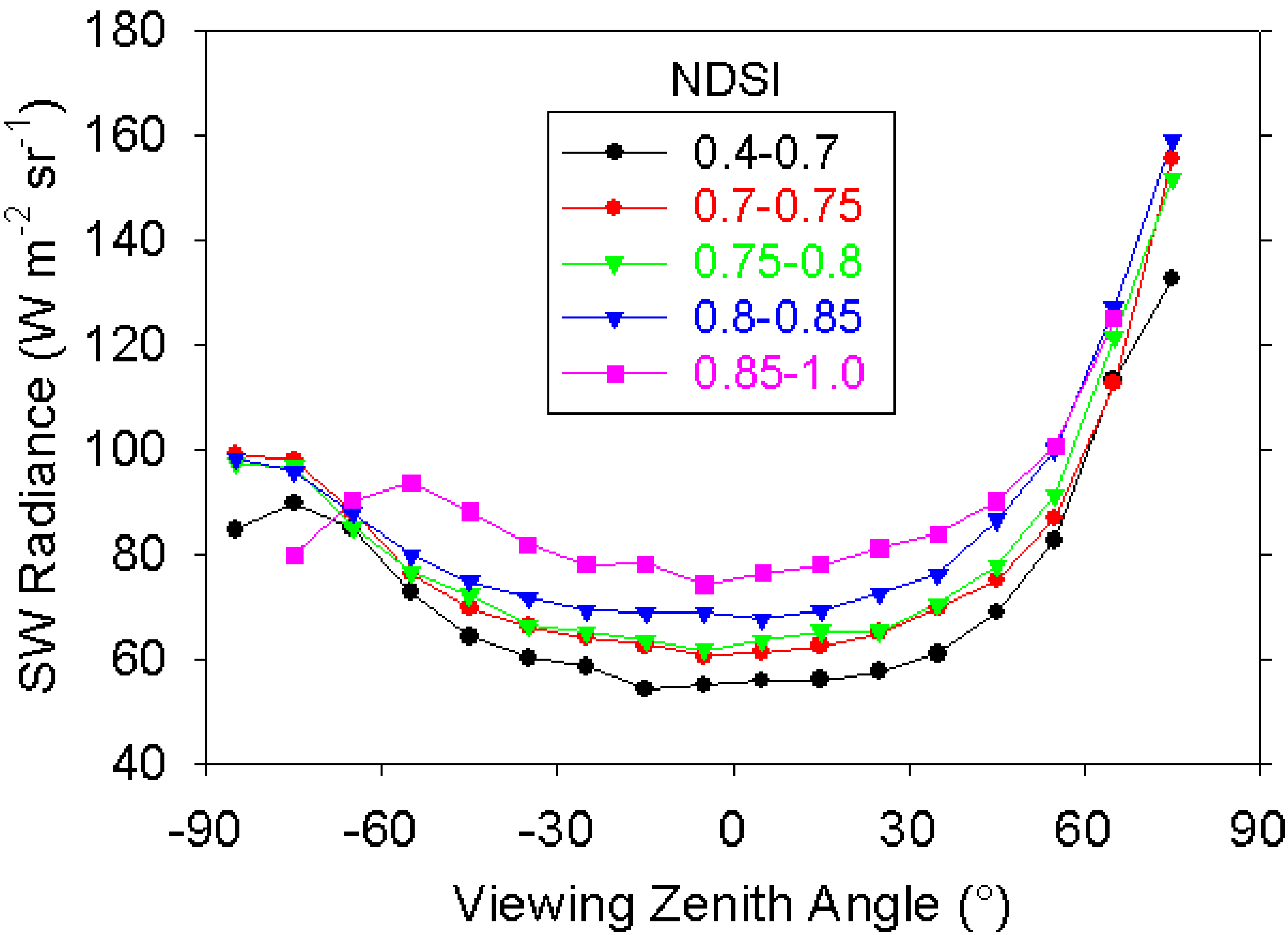


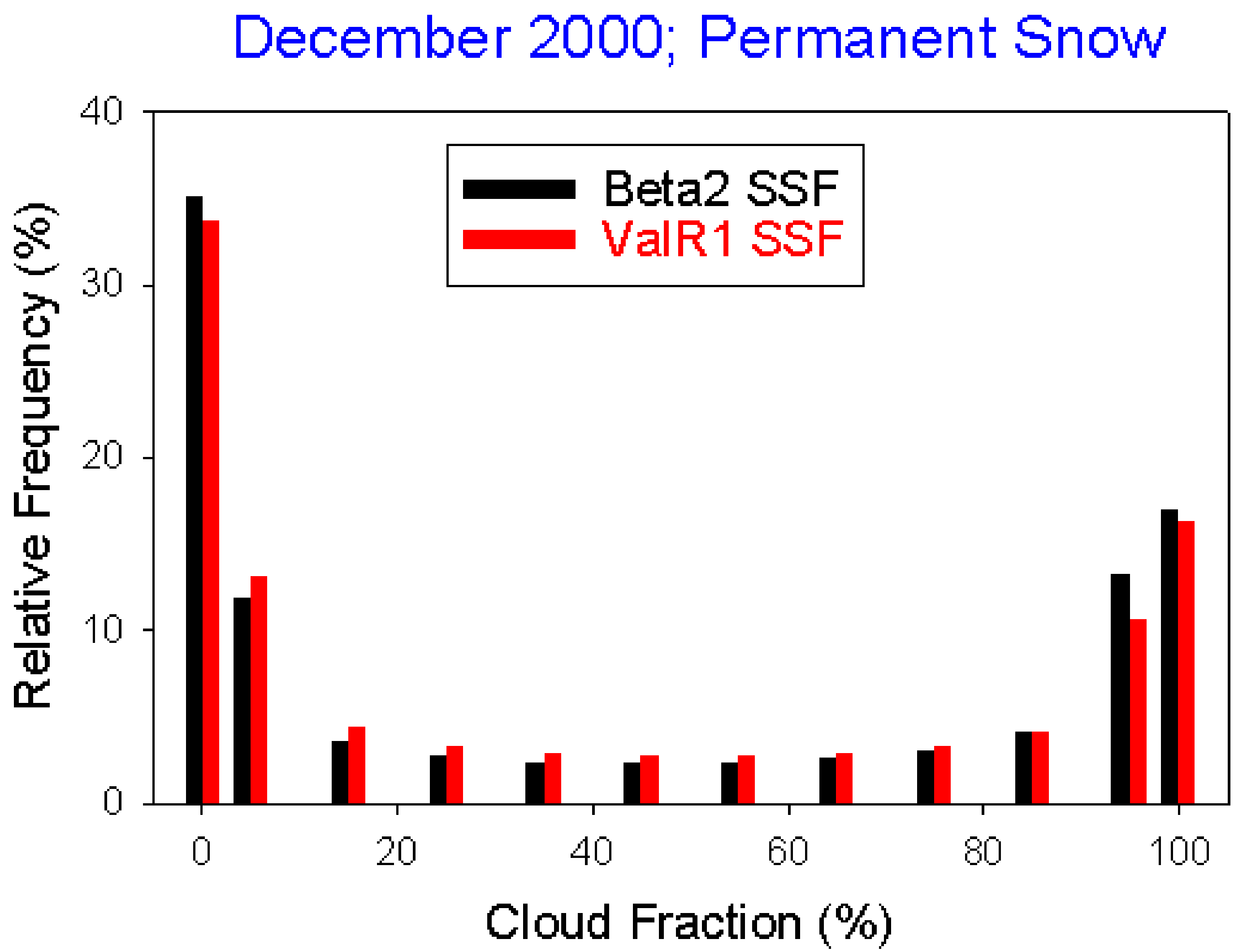
Klein et al., 2002


April, 2001
May, 2001
November, 2001
December, 2001
50
0
−50
50
100
150
200
250
300
350
0.4
0.5
0.6
0.7
0.8
0.9
1
NDSI

CERES SW Radiance vs θ and MODIS NDSI Snow Index

(θ_o=70°-80°; Principal Plane; Nov-Dec, 2000+Apr-May, 2001)





December 2000; Permanent Snow
Beta2 SSF
ValR1 SSF
Relative Frequency (%)
Cloud Fraction (%)
0
10
20
30
40
0
20
40
60
80
100

Terra LW & WN ADMs – Clear Scenes

Clear Ocean:

- Scene types defined by fixed discrete intervals of: precipitable water, lapse rate and skin temperature.

Clear Land and Desert:

- Similar to ocean but separate ADMs for forests, savannas, croplands/grasslands, tundra, open shrubs and barren deserts.

- Is it necessary (and practical) to stratify ADMs by relative azimuth angle over rough terrain?

Clear Snow:

- Stratify by permanent snow, fresh snow over land and sea ice.

Terra LW & WN ADMs – Cloudy Scenes

Clouds over Ocean:

Scene types defined by fixed discrete intervals of: precipitable water, cloud cover, surface-cloud temperature difference and cloud emissivity.

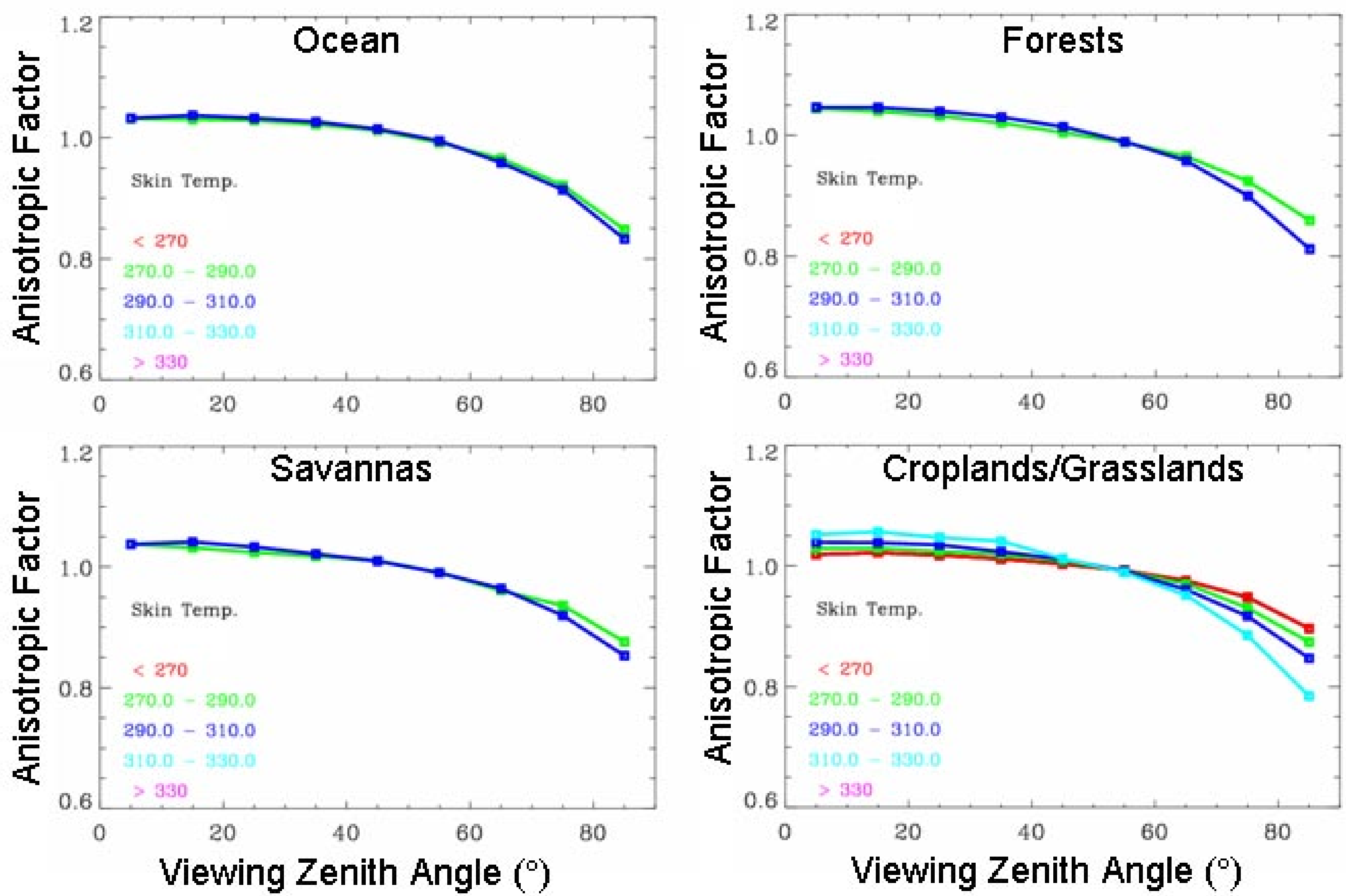
Clouds over Land and Desert:

Same parameters as for ocean.

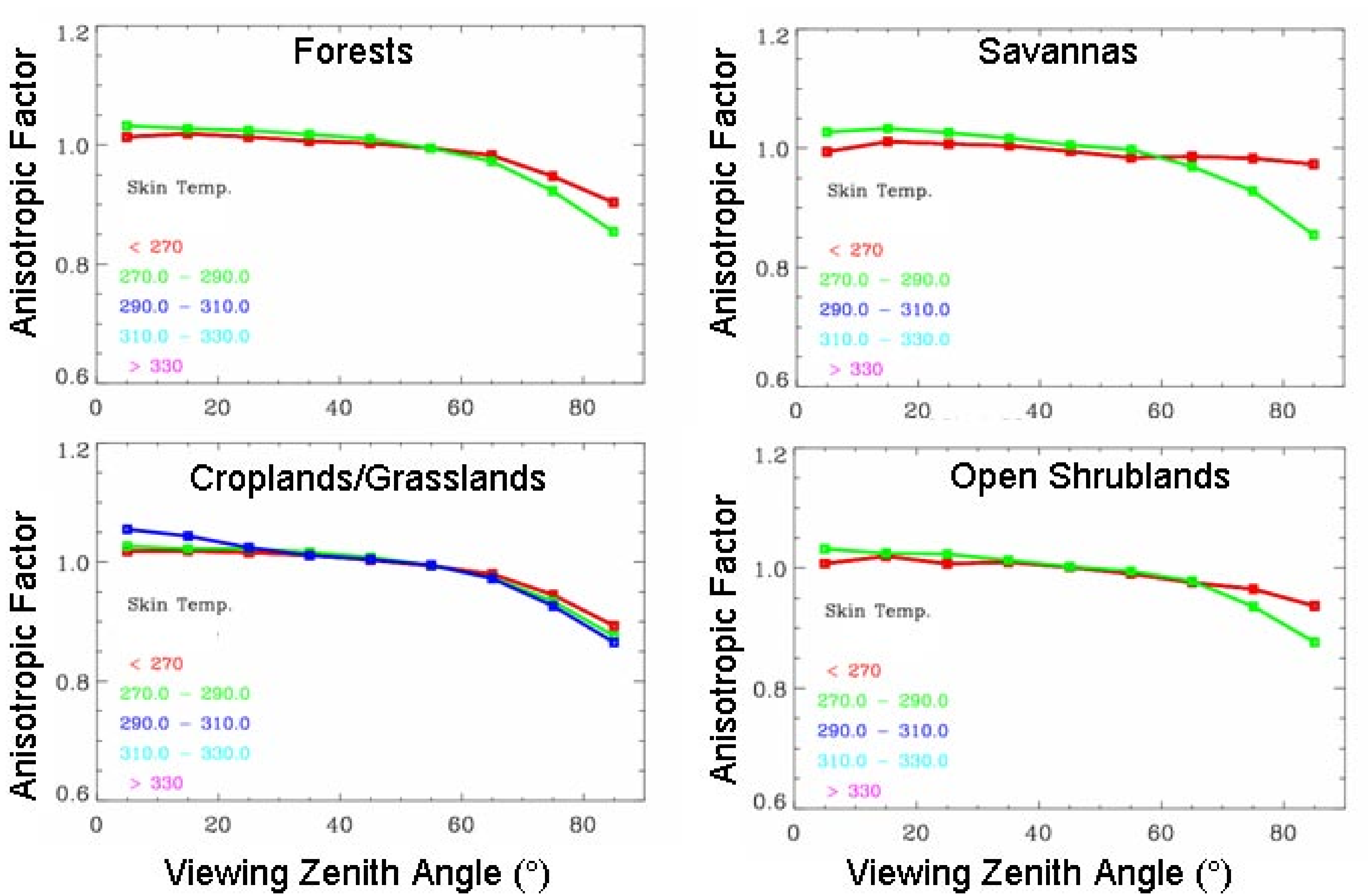
Clouds over Snow:

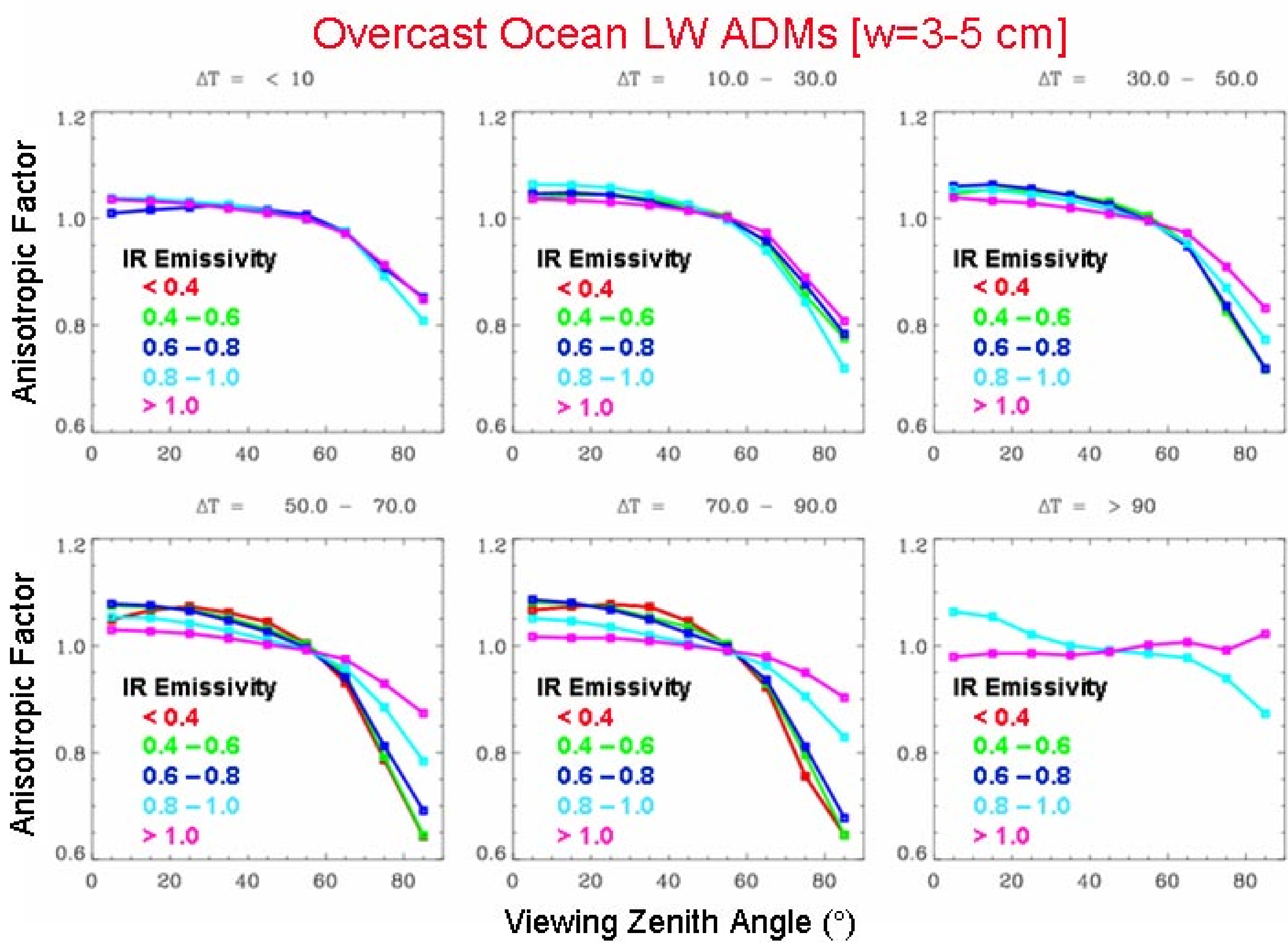
Fixed discrete intervals of cloud cover, surface-cloud temperature difference and cloud emissivity.

Clear LW ADMs [w=0-1 cm; T(sfc) - T(sfc-300mb)=15-30 K]



Clear LW ADMs [w=0-1 cm; T(sfc) - T(sfc-300mb) **< 15 K**]



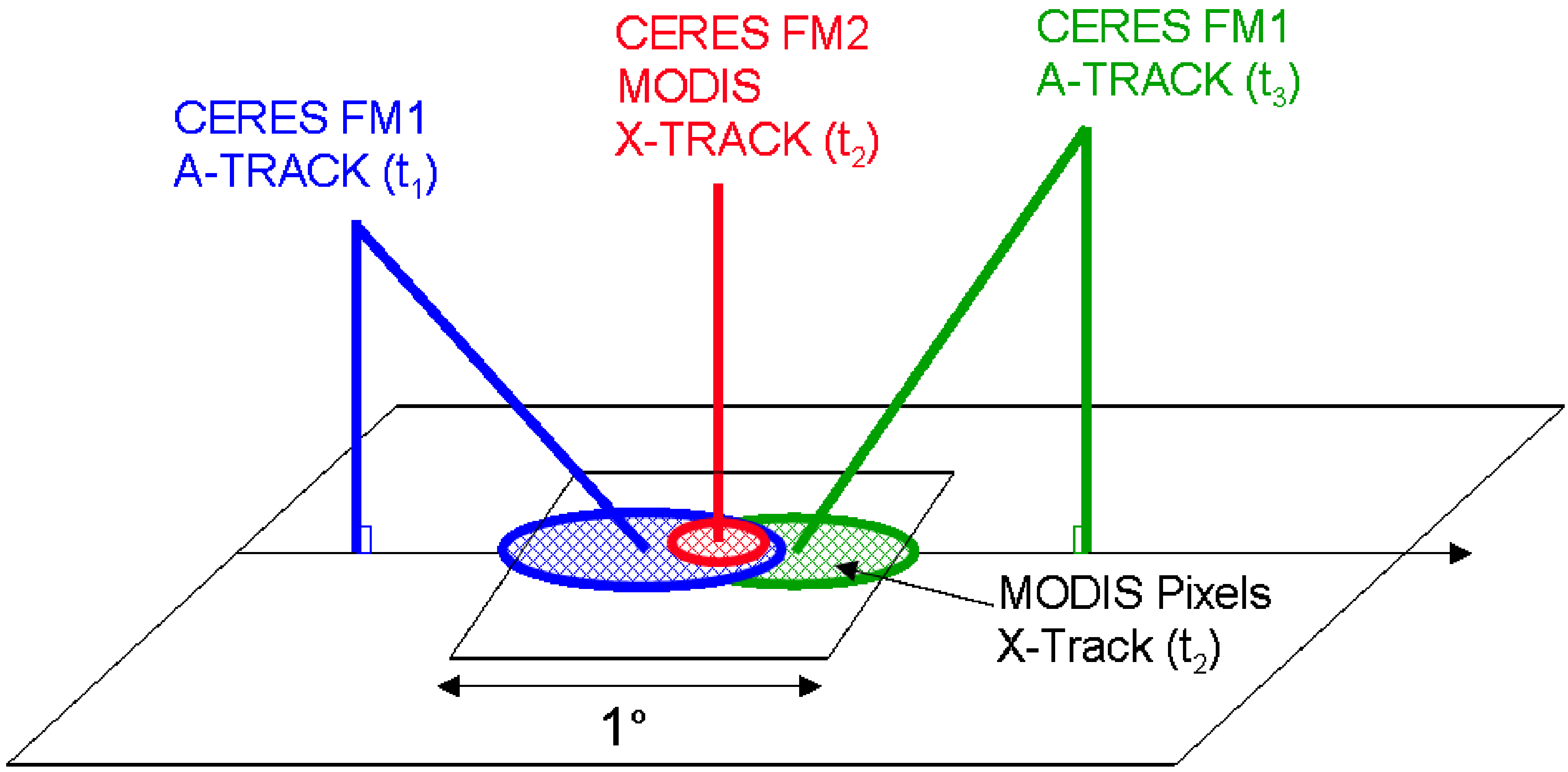


Overcast Ocean LW ADMs [w=3-5 cm]
ΔT = < 10
ΔT = 10.0 – 30.0
ΔT = 30.0 – 50.0
ΔT = 50.0 – 70.0
ΔT = 70.0 – 90.0
ΔT = > 90
Anisotropic Factor
Viewing Zenith Angle (°)
IR Emissivity
< 0.4
0.4 – 0.6
0.6 – 0.8
0.8 – 1.0
> 1.0
0.6
0.8
1.0
1.2
0
20
40
60
80

Regional Instantaneous TOA Flux Consistency Tests

1° Regional Instantaneous SW TOA Flux Consistency Test

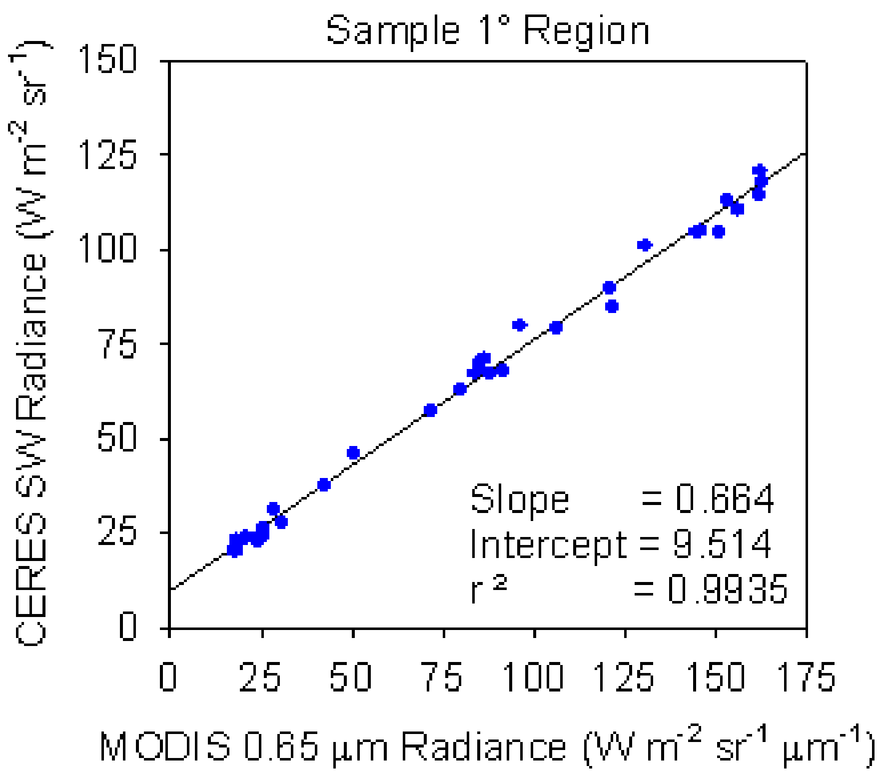
Objective: Compare ADM-derived TOA fluxes over 1° regions from different viewing geometries. Are TOA fluxes consistent?

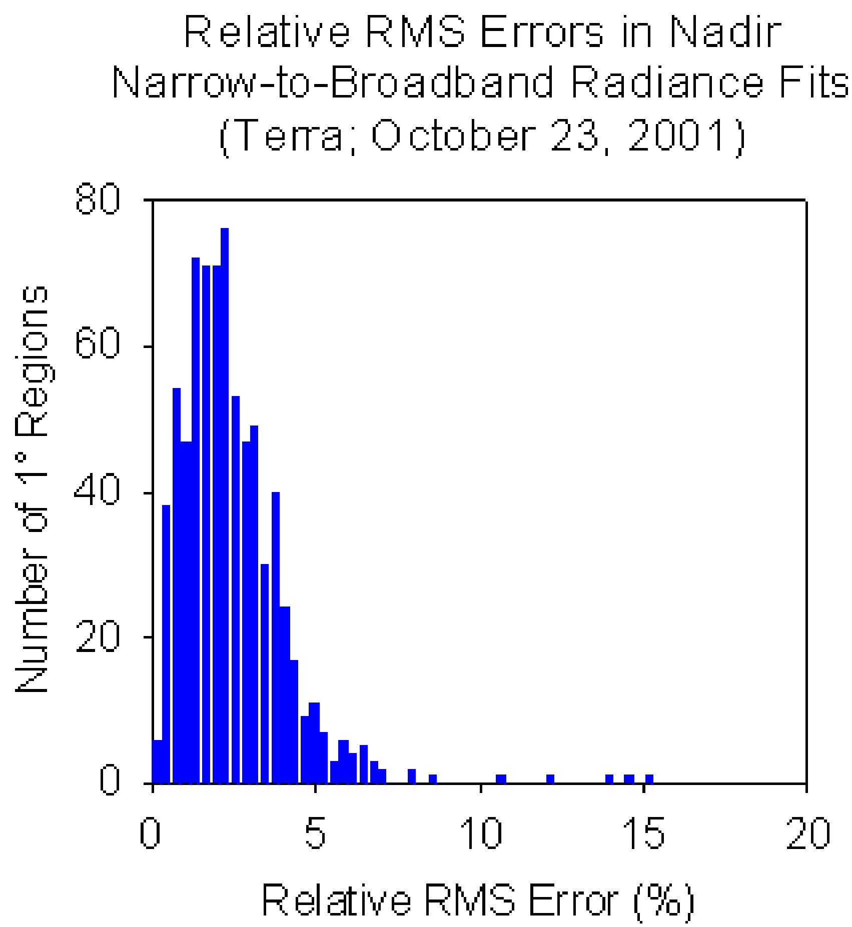


1° Regional Instantaneous SW TOA Flux Consistency Test

Approach: For every 1° region:

(1) Use nadir CERES footprints to train MODIS imager to produce broadband SW radiances over each CERES footprint within 1° region (linear fit).





(2) Convert imager “broadband” radiance over every CERES alongtrack footprint to a flux by calling CERES ADM module.

=> Imager sees CERES alongtrack footprints from nadir direction only.

(3) For every 1° region, compare nadir imager TOA fluxes with alongtrack CERES TOA fluxes.

=> Since imager and CERES measurements are collocated, spatial matching errors are reduced with this technique.

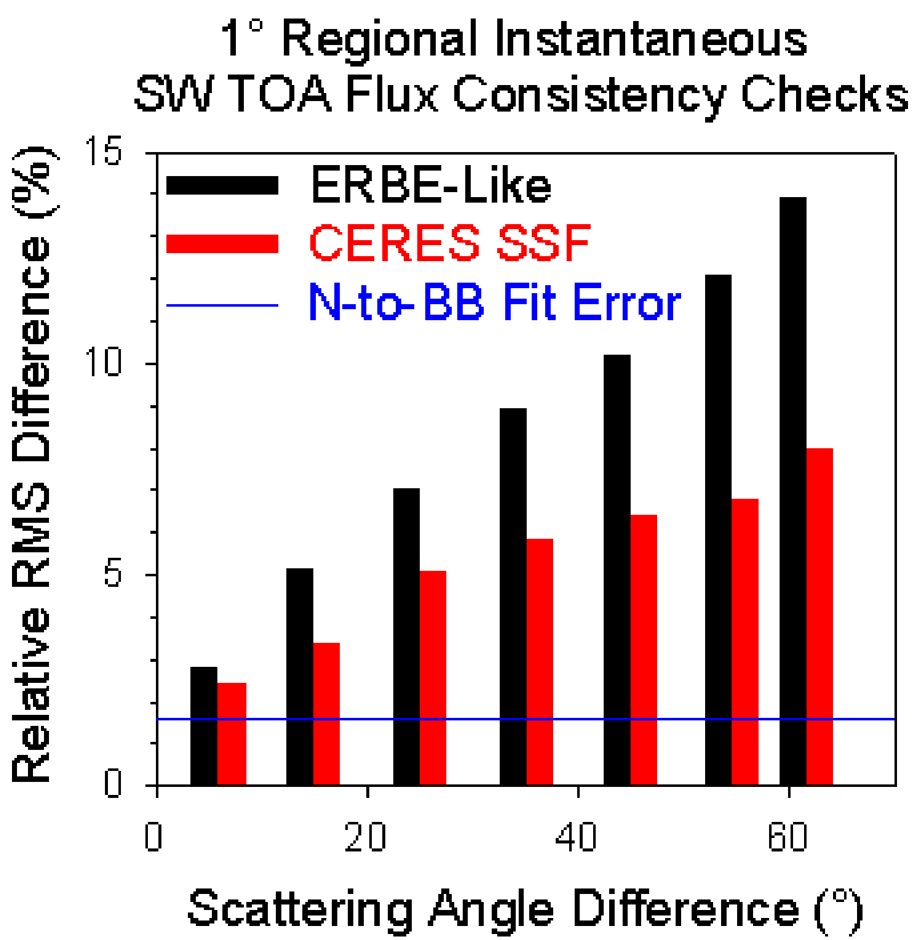
=> Main Sources of Error:

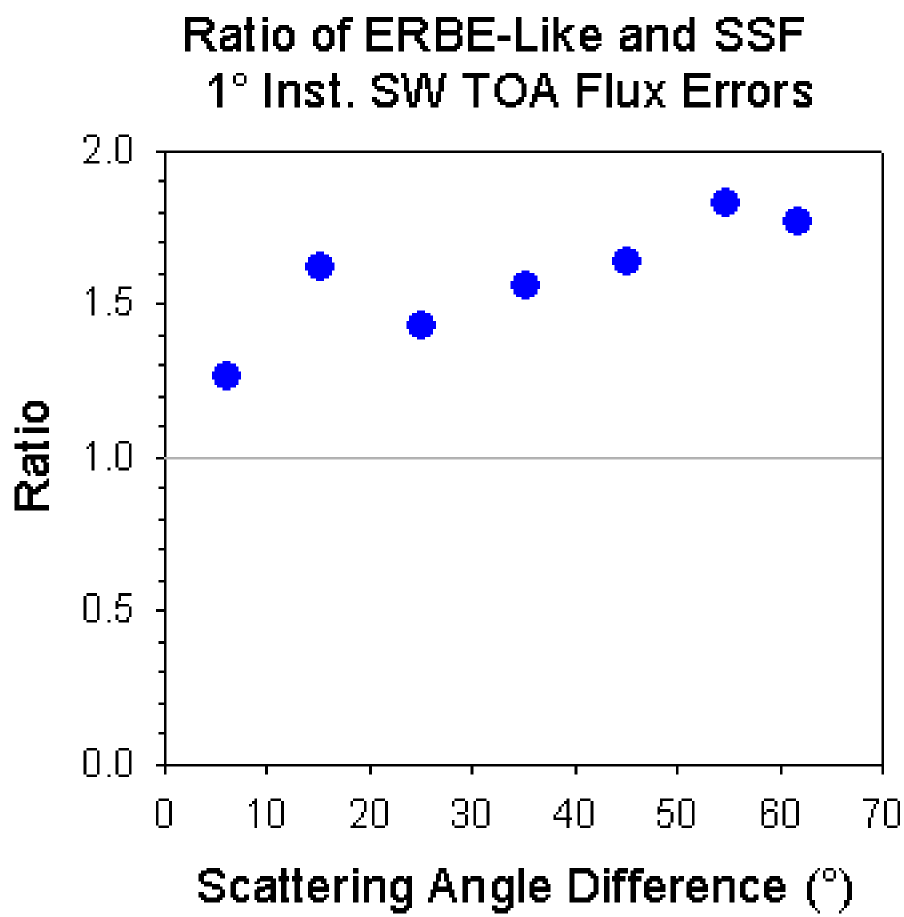
i) Radiance-to-flux conversion (ADMs)

ii) Narrow-to-broadband conversion

1° Regional Instantaneous SW TOA Flux Consistency Test

Results: Based on 1 day of A-track and X-track CERES/Terra data.





Summary

- CERES/Terra ADMs:
  - Based on 2 years of measurements.
  - Increase angular bin resolution.
  - Increase number of scene types relative to TRMM.
  - New approach for “continuous” SW ADMs for clouds.
  - Empirical SW and LW ADMs over snow and sea ice.

- Early CERES SSF instantaneous regional TOA flux consistency checks show a factor of 1.8 improvement over ERBE-Like.

TOA Flux Working Group Agenda

1. Inversion of SW and LW Radiances into TOA Fluxes using Artificial Neural Network Simulation – Konstantin Loukachine
2. Plans for Terra ADM Development: ADM Parameter Studies – Nitchie Manalo-Smith
3. Some Preliminary Model Results of Longwave Anisotropy from CERES TRMM and Terra – A.V.Gambheer
4. Progress Report of Snow ADMs for TERRA– Seiji Kato
5. Scheme for retrieval of ice clouds optical thickness and bulk phase functions using multi-angular data from POLDER.– Wenbo Sun
6. GERB inversions: Methods and Plan for Validation – Nicolas Clerbaux
7. Theoretical Simulations of ADMs based on Sigmoidal Fits – Lin Chambers