Comparison of MODIS/CERES Radiances with Model Over Snow and Snow Grain Size Determination for CERES SARB Retrieval

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Background:

CERES SARB (***S**urface and **A**tmospheric **R**adiation **B**udget*) retrieved TOA and surface albedo (*CRS Ed2b*) over snow have shown significant bias to the surface (ARM, CMDL) and TOA (CERES) observations.

Except for the surface roughness effect, a possible major error source is **the surface albedo, especially the spectral shape**, used in the retrieval.

The snow surface albedo LUT in SARB retrieval was created by the radiative transfer model, so model validation and improvements are required.

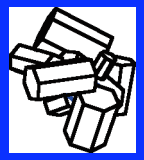
Outline:

1. Snow optical properties.
2. Validation of radiative transfer model with quality surface measurements (*Hudson et al., 2006*).
3. Comparison with MODIS/CERES radiances.
4. Model application to snow grain size retrieval for CERES SARB.

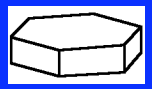
1. Snow Optical Properties

Compare the snow optical properties (extinction, absorption, and scattering asymmetry factor) for the four snow particle shapes:

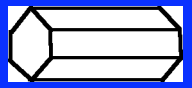
Sphere



Aggregate

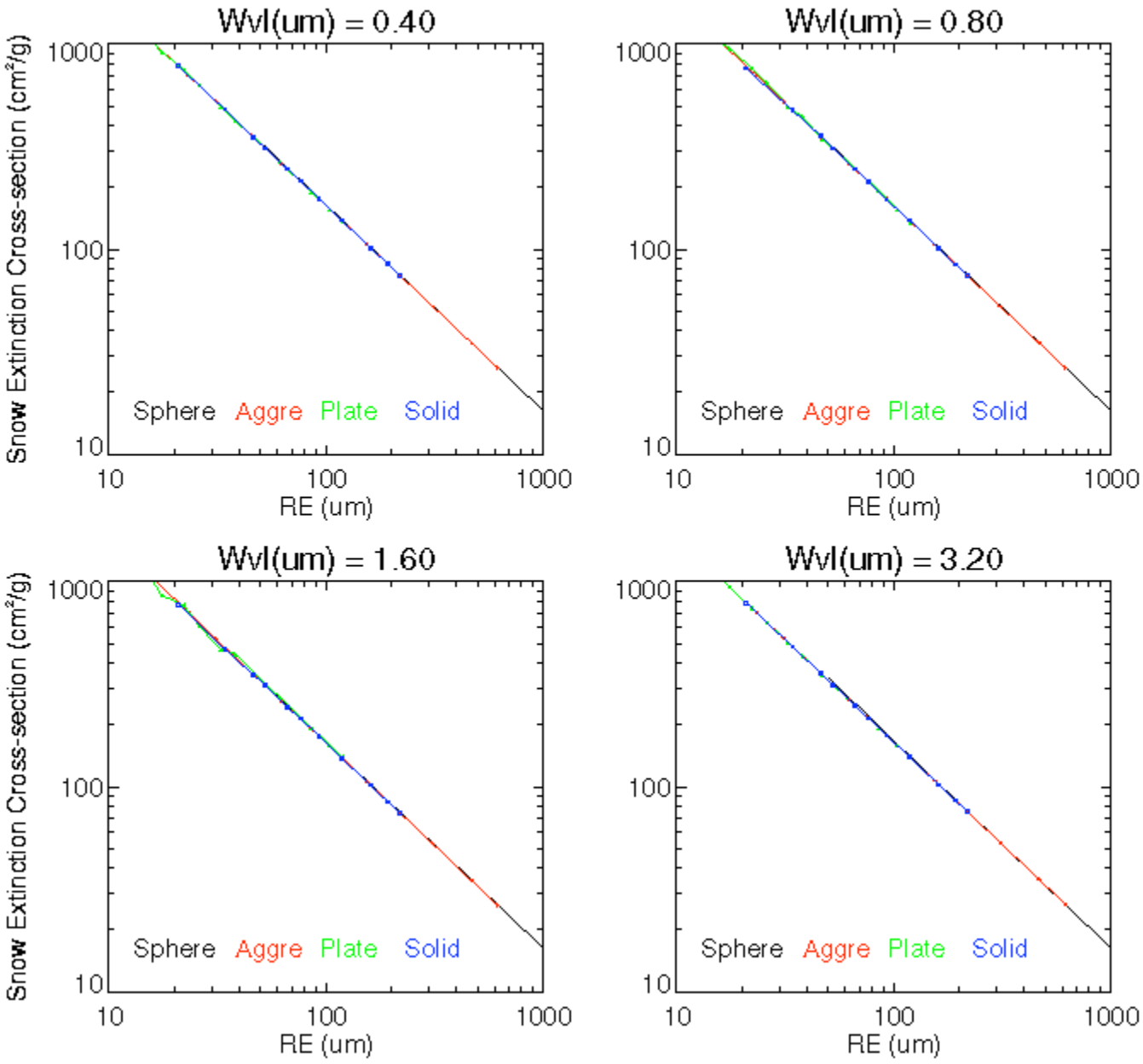


Plate



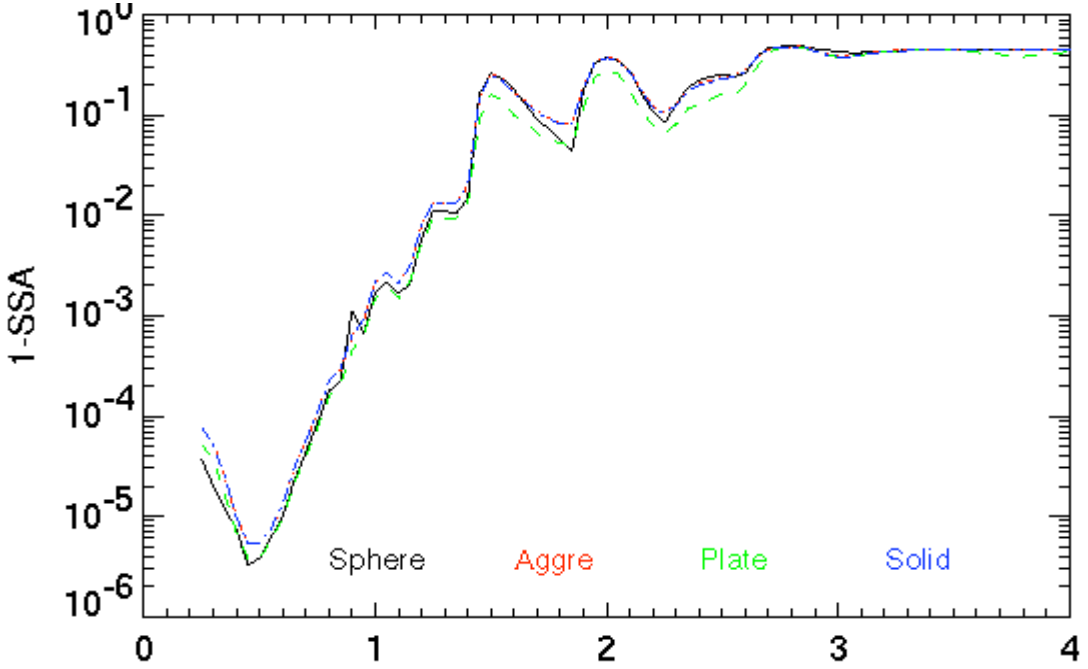
Solid column

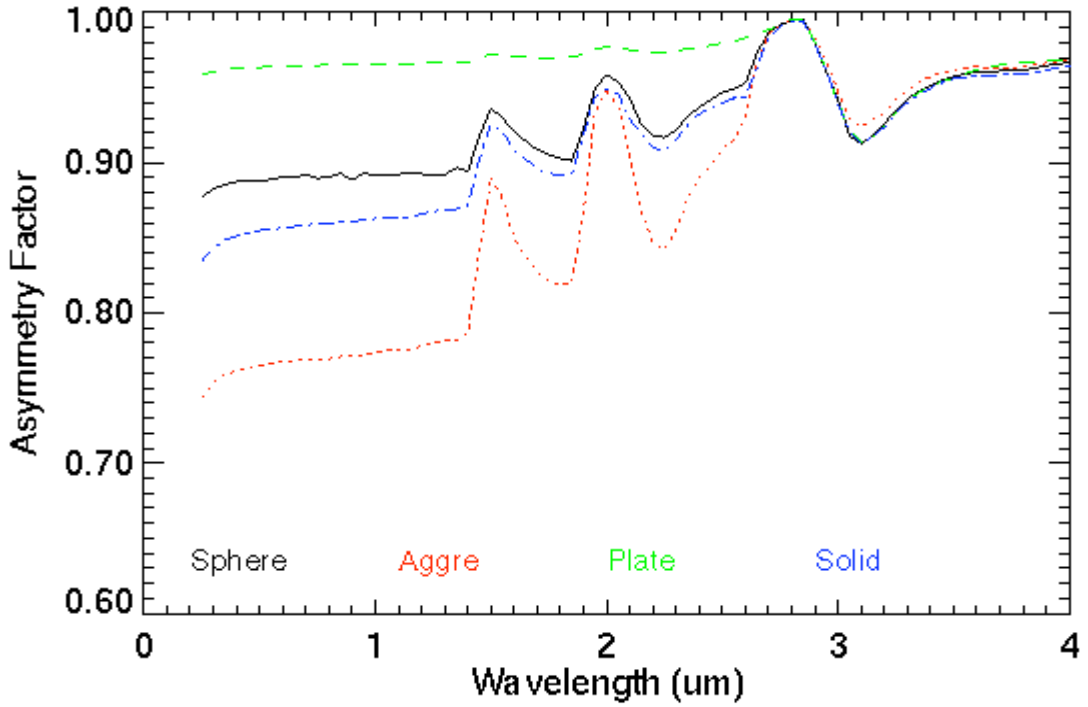
Effective radius: Re = 0.75 (Volume/Project-area)



Extinction cross-section for unit mass of snow (cm^2/g).

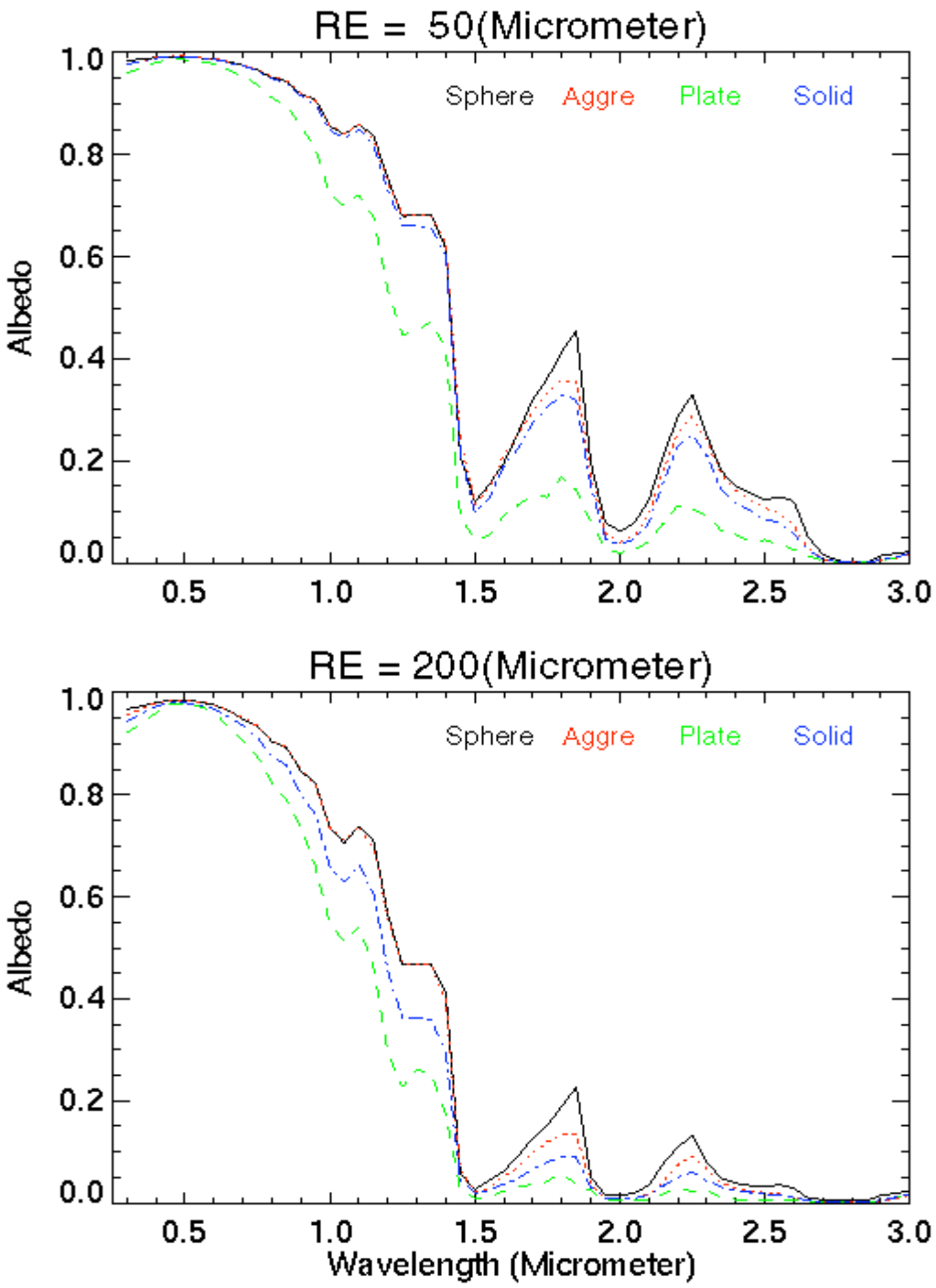
Re = 0.75V/A





Single scattering co-albedo and asymmetry factor for the four particle shapes as a function of wavelength.

Re = 100 (micrometer)



Comparison of the albedo for the four particle shapes.

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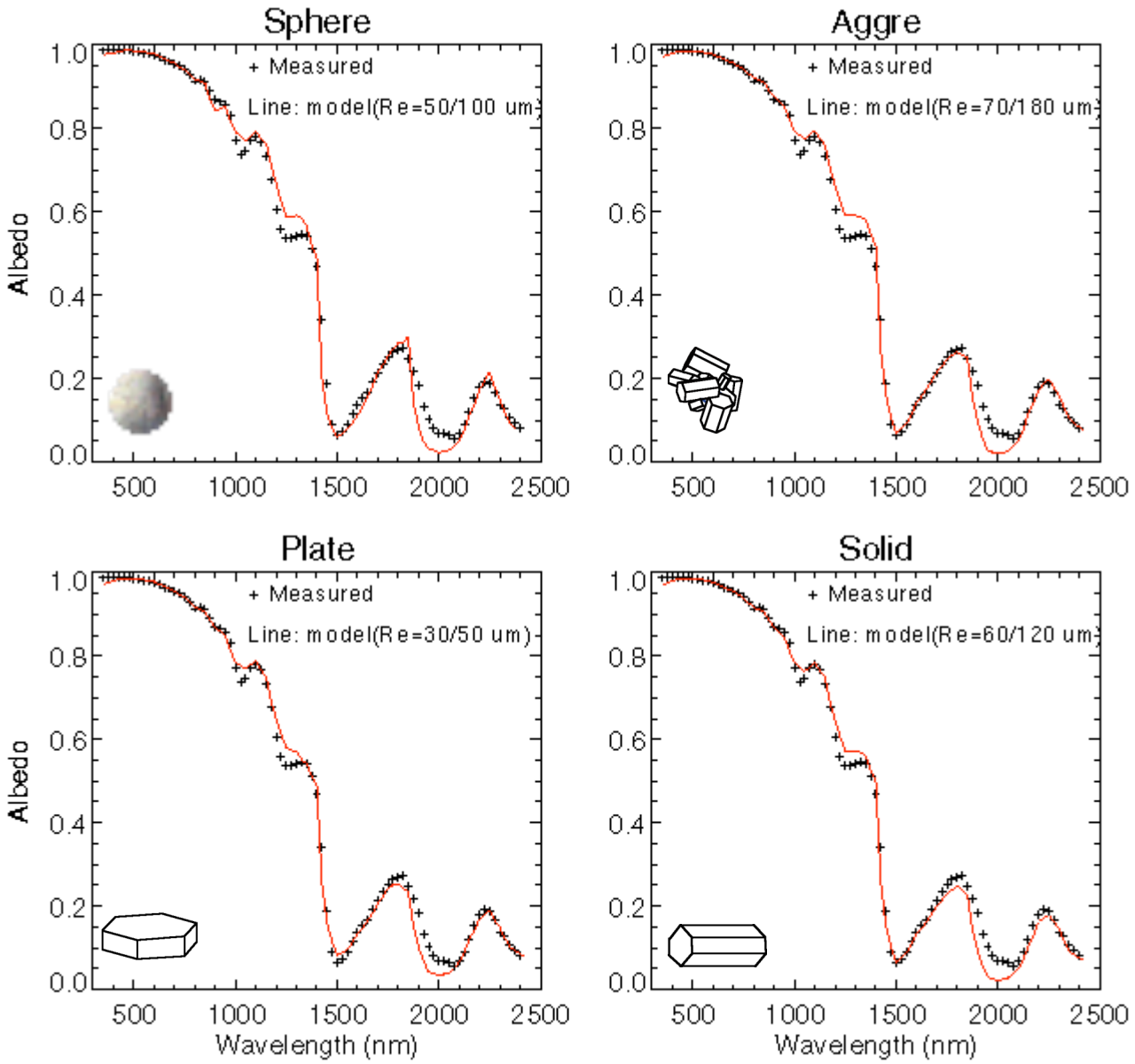
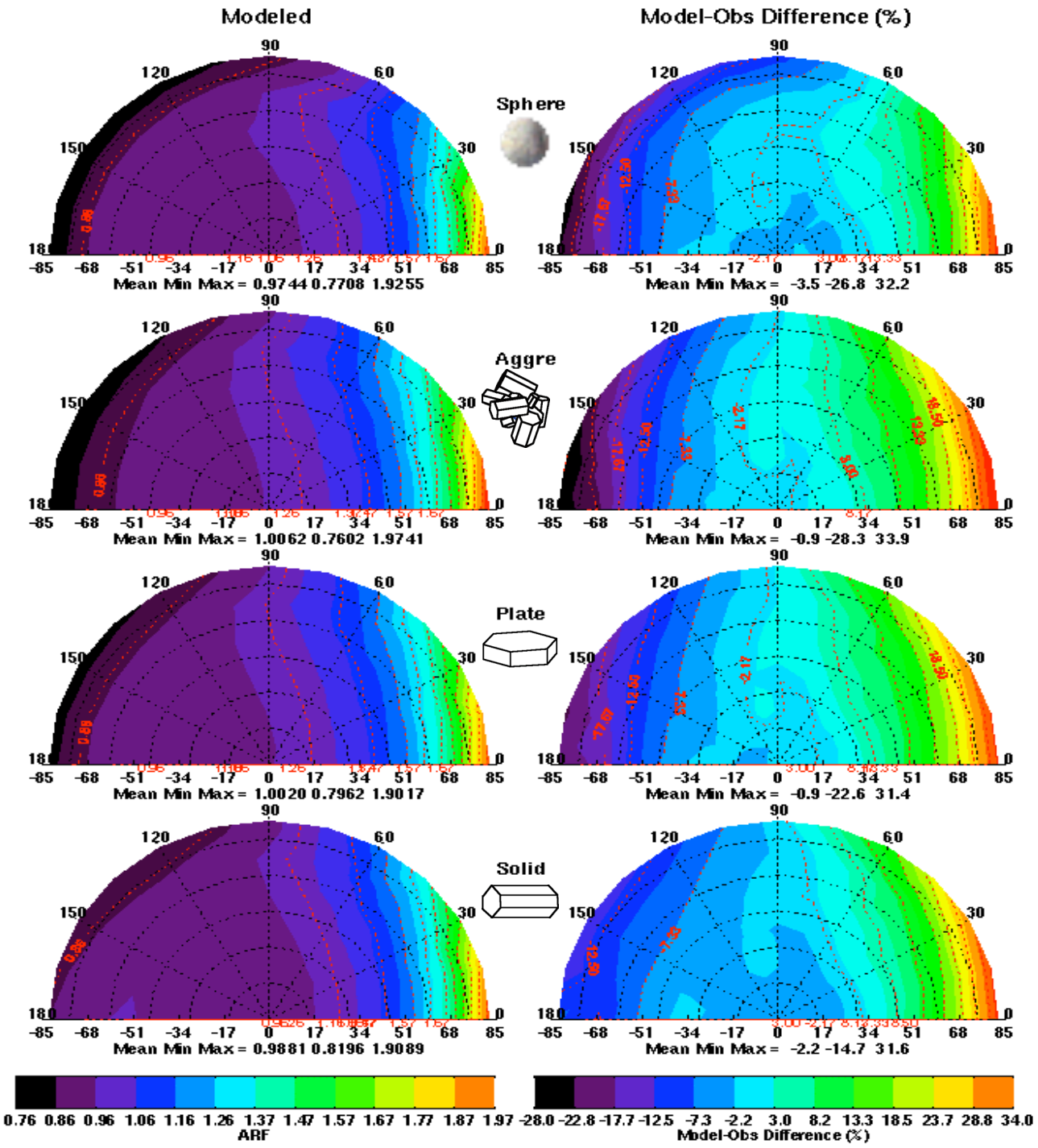
2. Comparison With Surface Measurements

Compare the measured spectral surface albedo and the anisotropic reflectance factor (ARF) (i.e., radiance distribution or ADM) with model for the four snow particle shapes.

Measurements are from Dome C, Antarctic by *Hudson et al*. (2006).

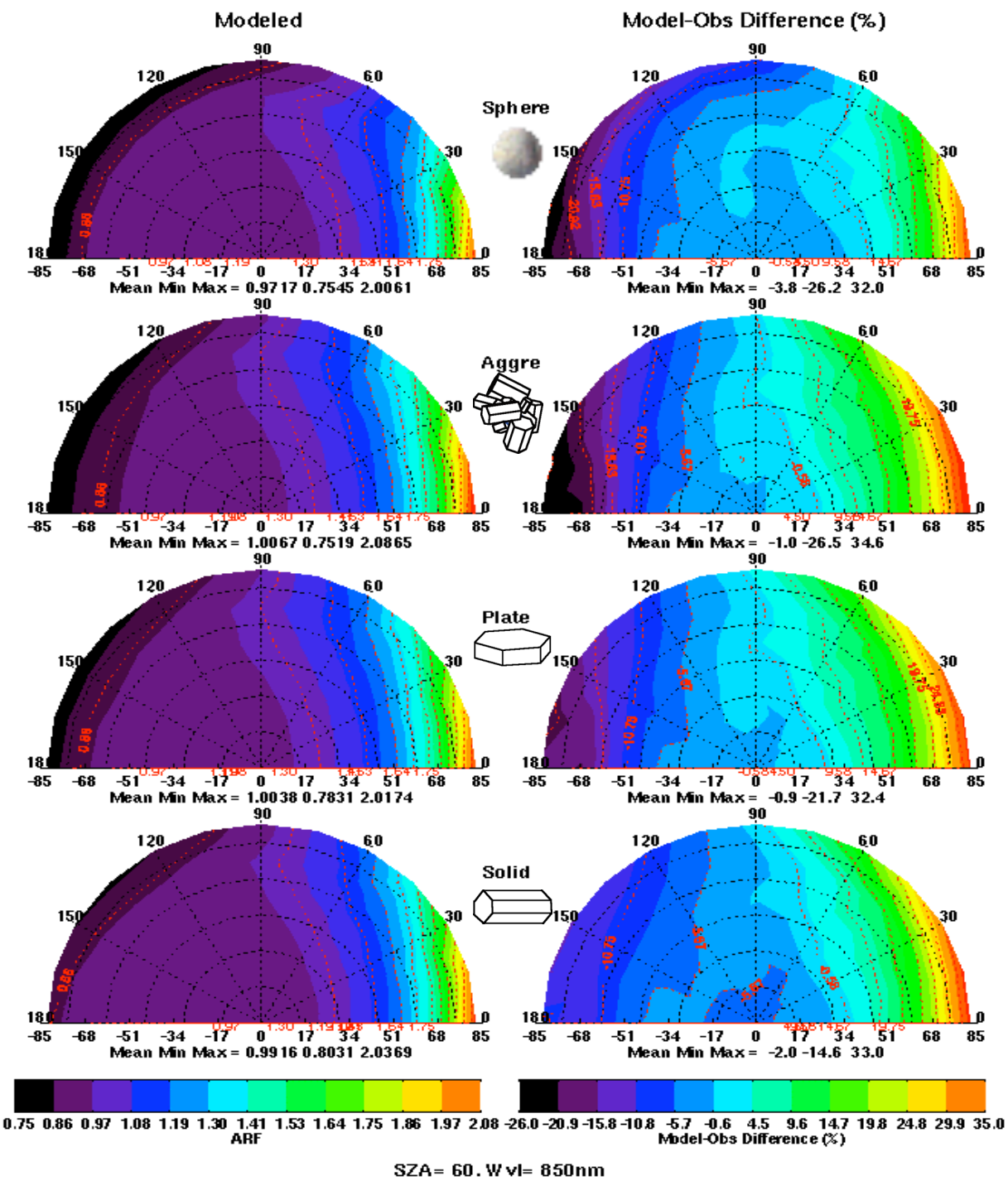


Snow spectral albedo can be matched well with a two-layer snow model regardless of the particle shape.



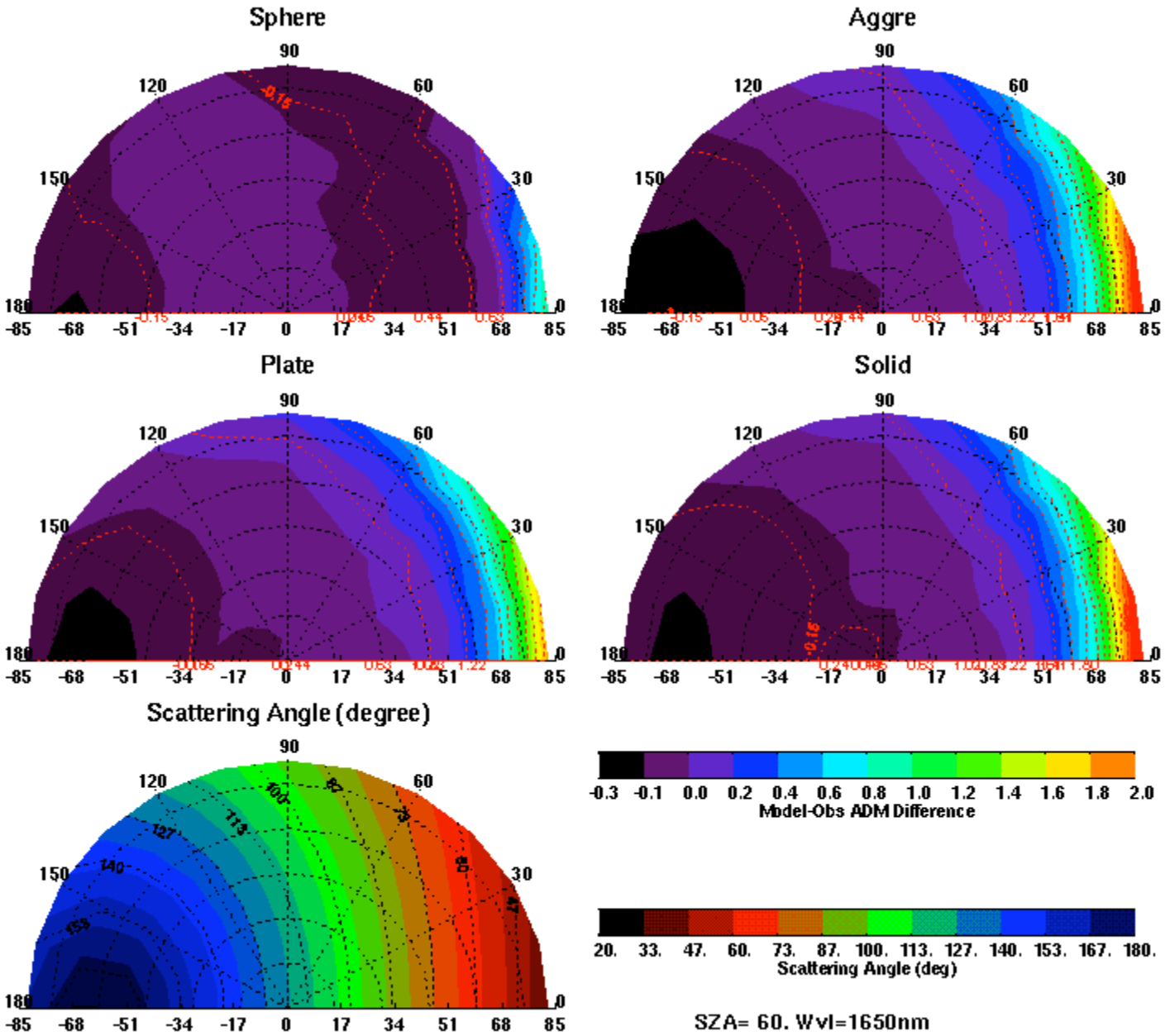
Modeled surface radiance distribution (left) and relative difference from surface measurement (right) for the four particle shapes.

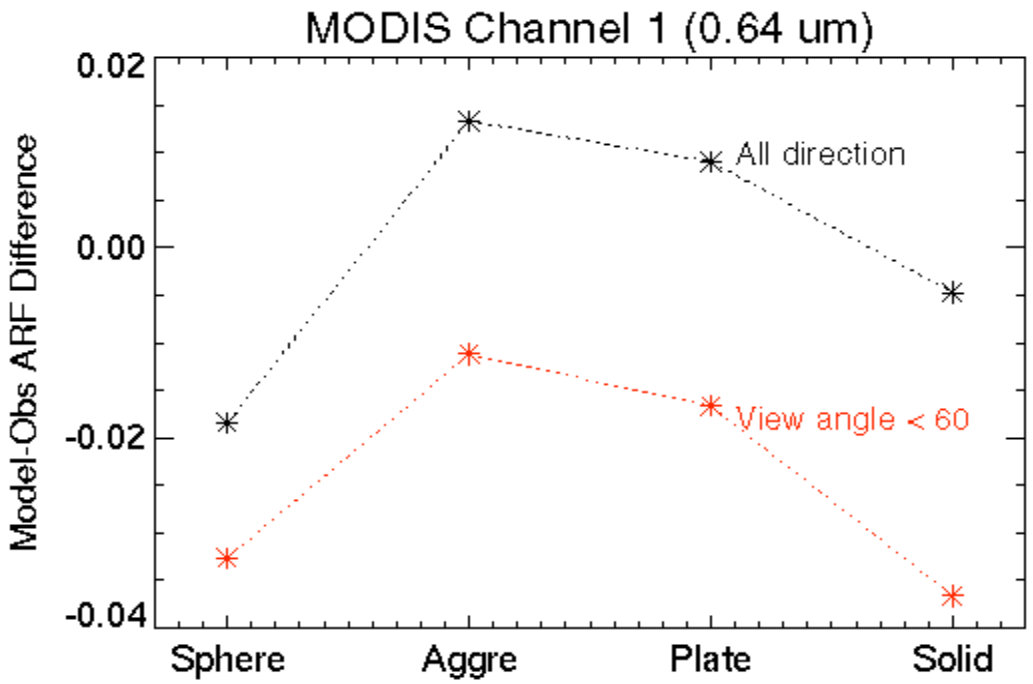
The same two-layer models as used for the spectral albedo simulations are used.

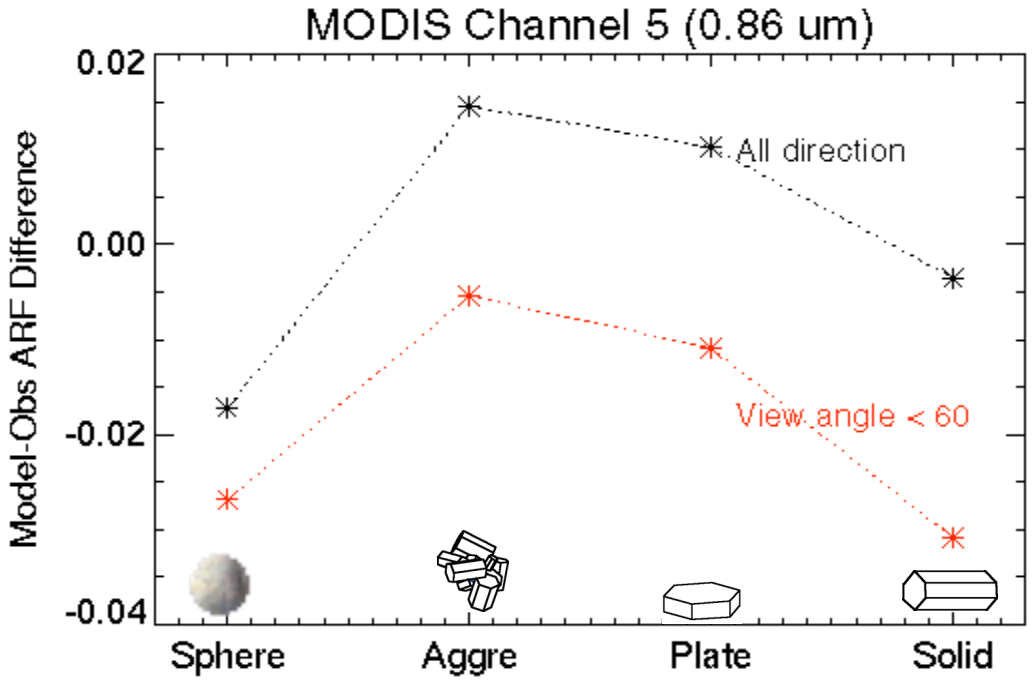

Modeled
Model-Obs Difference (%)
Sphere
Aggre
Plate
Solid
Mean Min Max = 0.9717 0.7545 2.0061
Mean Min Max = -3.8 -26.2 32.0
Mean Min Max = 1.0067 0.7519 2.0865
Mean Min Max = -1.0 -26.5 34.6
Mean Min Max = 1.0038 0.7831 2.0174
Mean Min Max = -0.9 -21.7 32.4
Mean Min Max = 0.9916 0.8031 2.0369
Mean Min Max = -2.0 -14.6 33.0
0.75 0.86 0.97 1.08 1.19 1.30 1.41 1.53 1.64 1.75 1.86 1.97 2.08
ARF
-26.0 -20.9 -15.8 -10.8 -5.7 -0.6 4.5 9.6 14.7 19.8 24.8 29.9 35.0
Model-Obs Difference (%)
SZA= 60. Wvl= 850nm

ARF difference at 1.65um for the four particle shapes.

Scattering angle




MODIS Channel 1 (0.64 um)
Model-Obs ARF Difference
0.02
0.00
-0.02
-0.04
All direction
View angle < 60
Sphere
Aggre
Plate
Solid


MODIS Channel 5 (0.86 um)
Model-Obs ARF Difference
0.02
0.00
-0.02
-0.04
All direction
View angle < 60
Sphere
Aggre
Plate
Solid

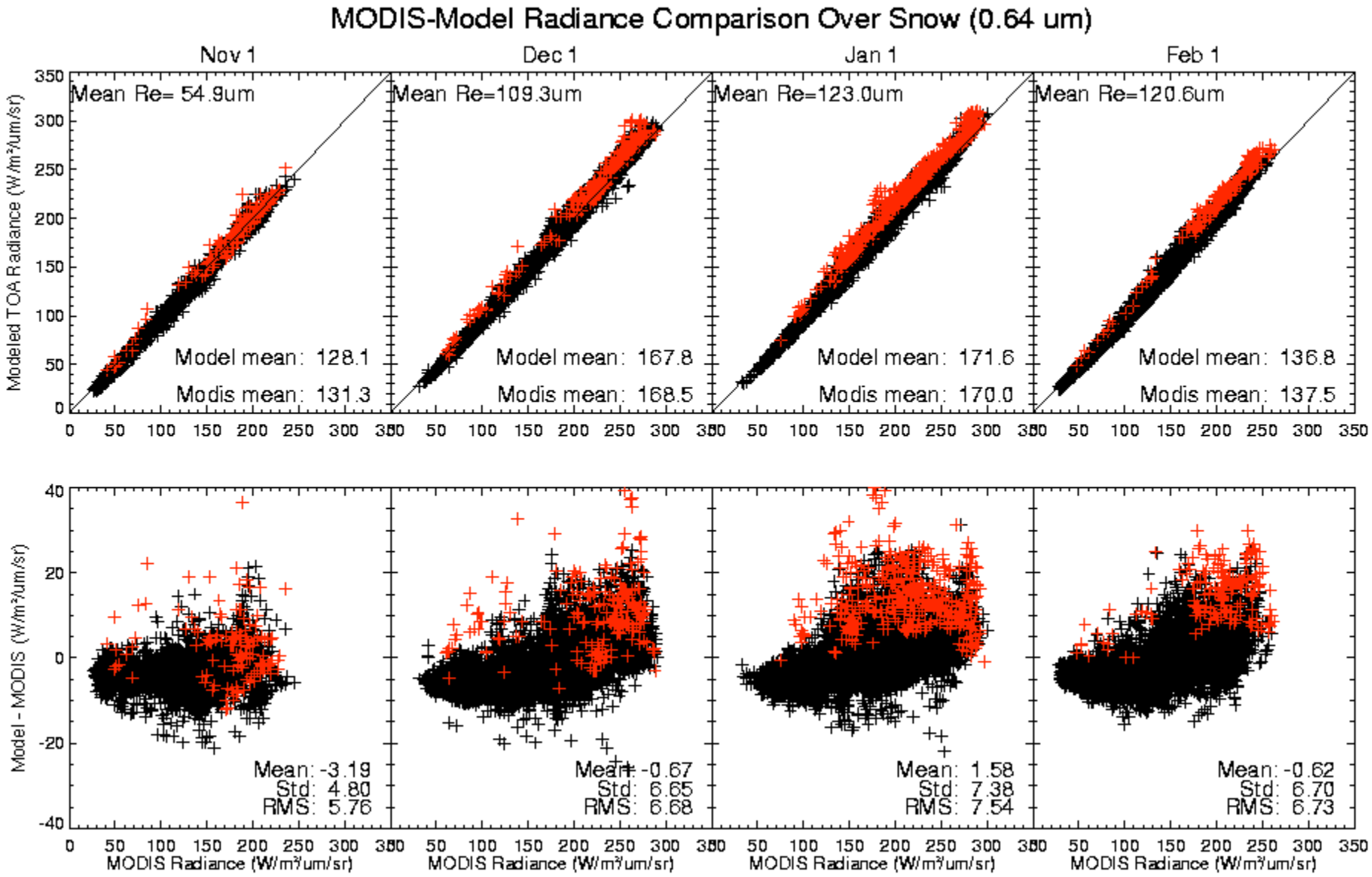
3. Comparison of MODIS/CERES Radiances With Model Simulation

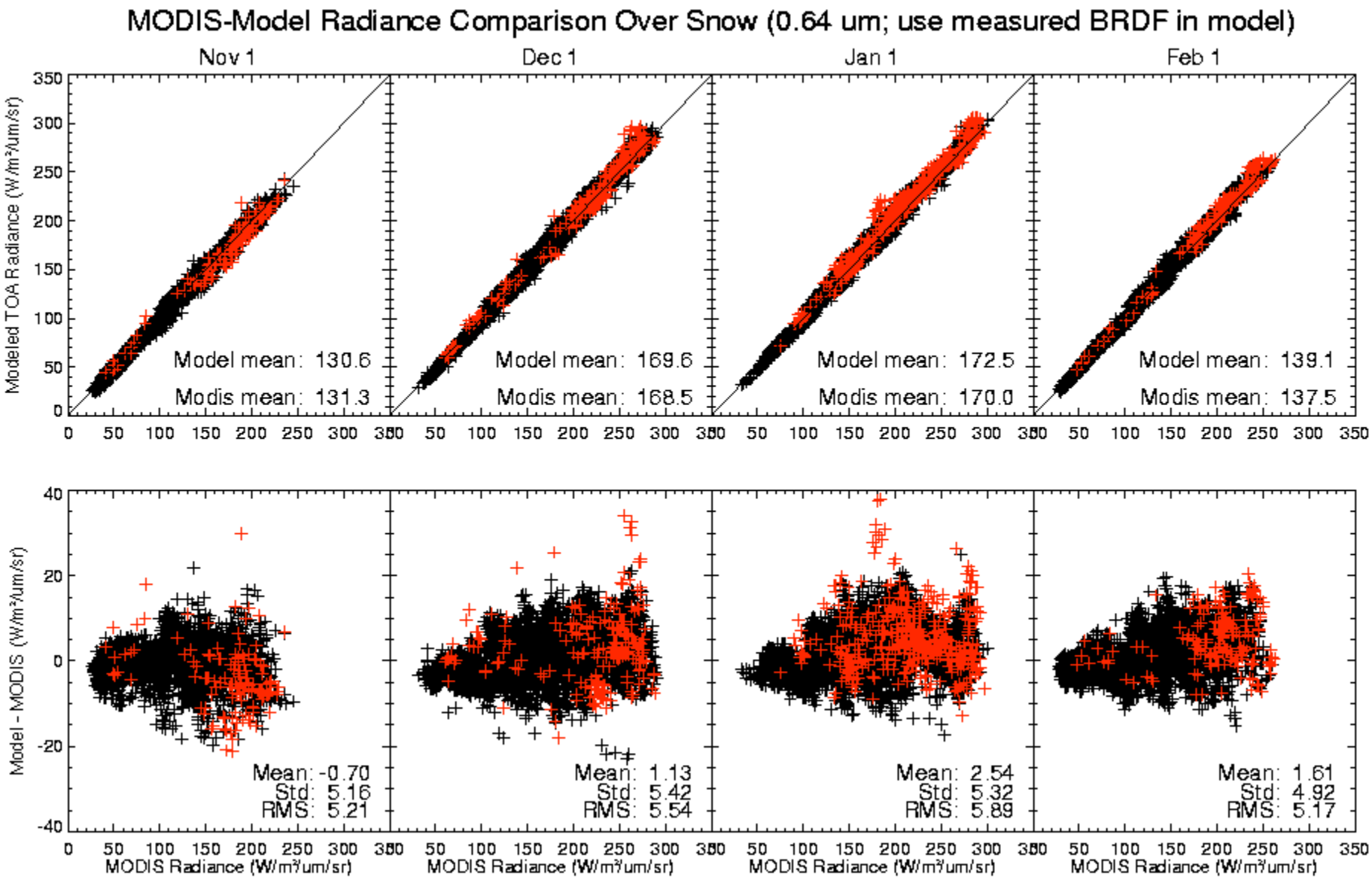
is selected for the radiative transfer simulations of MODIS/CERES radiances.

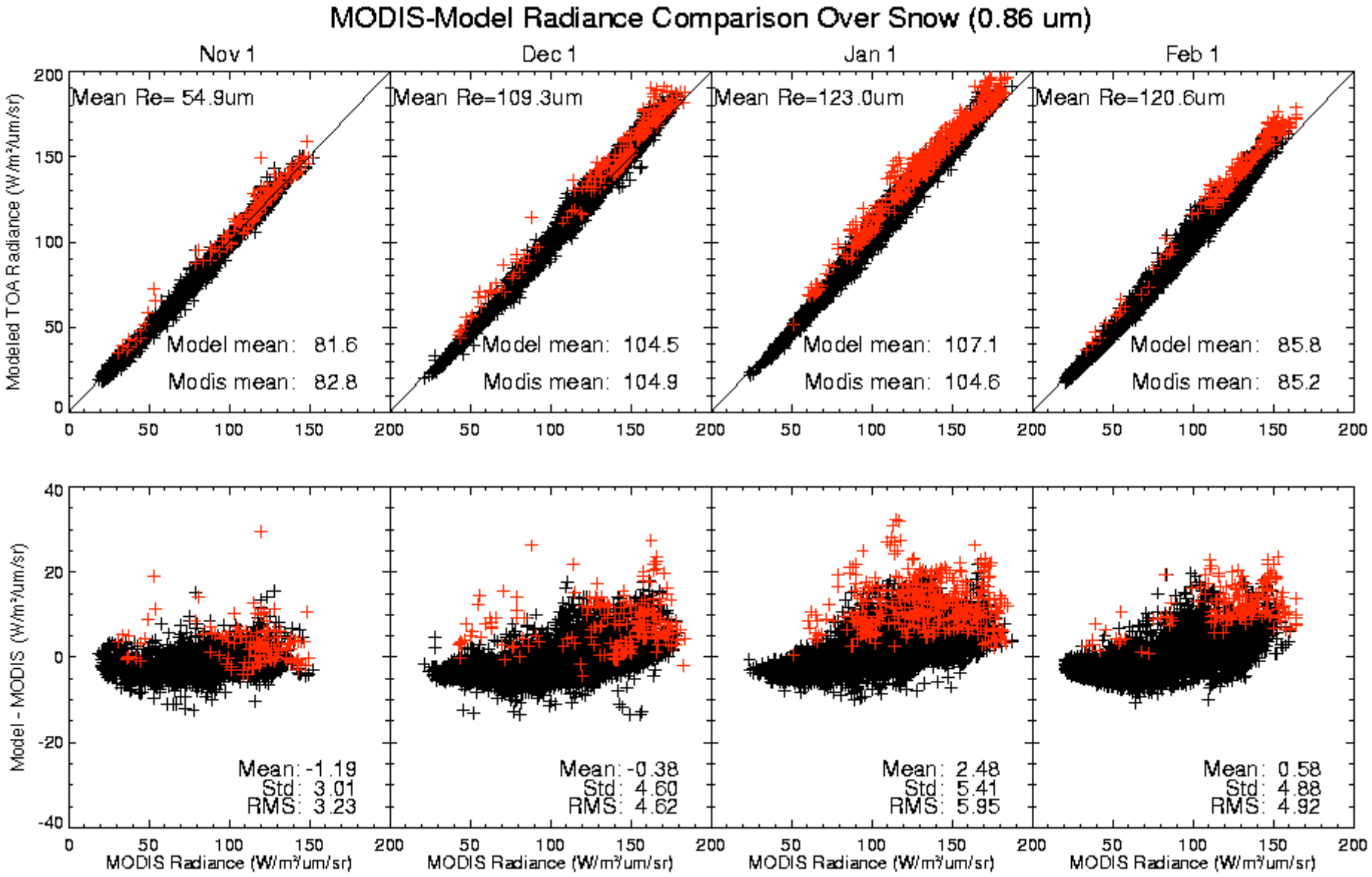
CERES/MODIS data selection criteria:

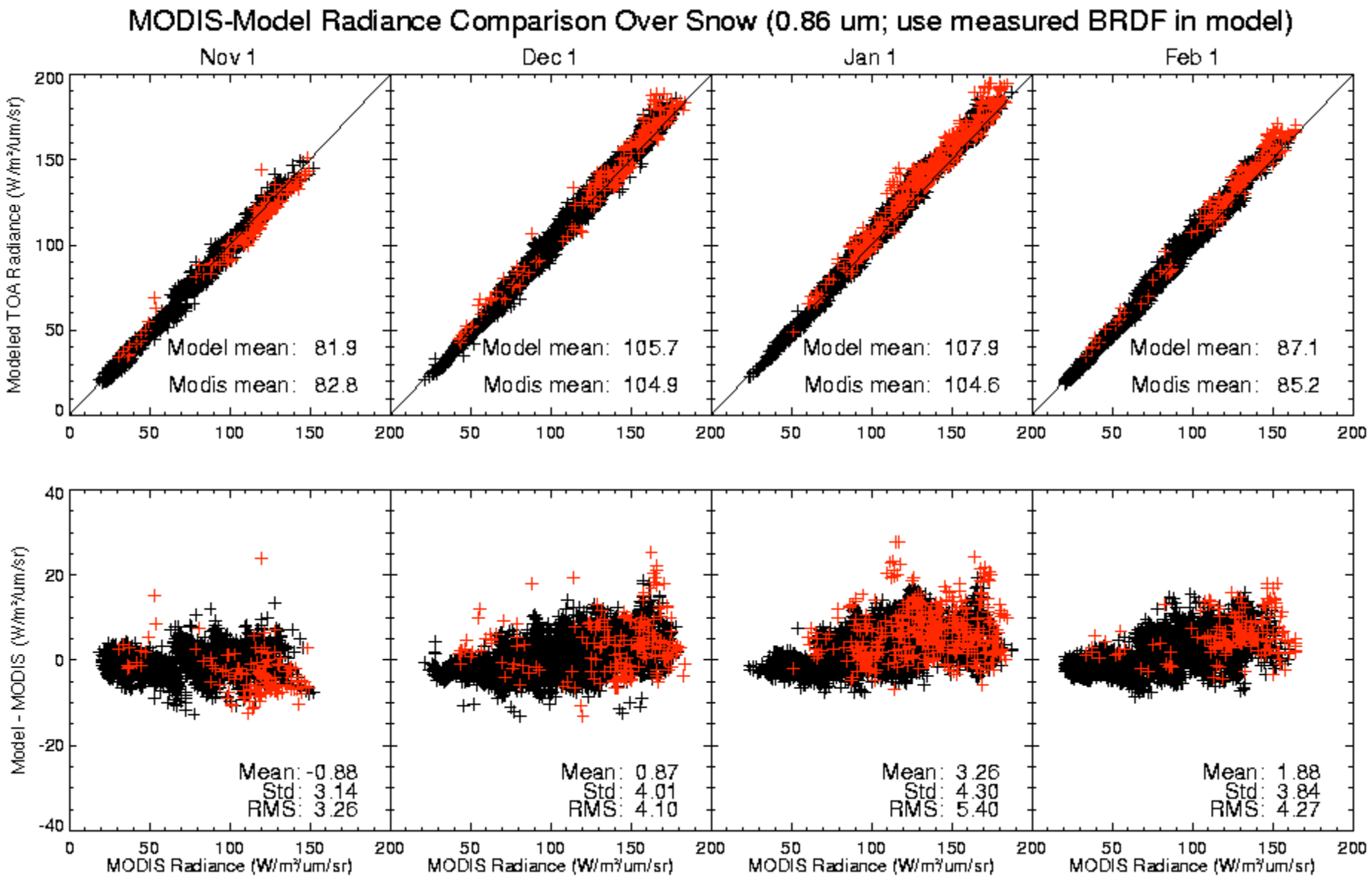
1) *Clear fraction = 100%*
2) *100% snow in each footprints*
3) *Relative STD of imager radiances < 3%*
4) *T_surface < 270°K for snow surface*

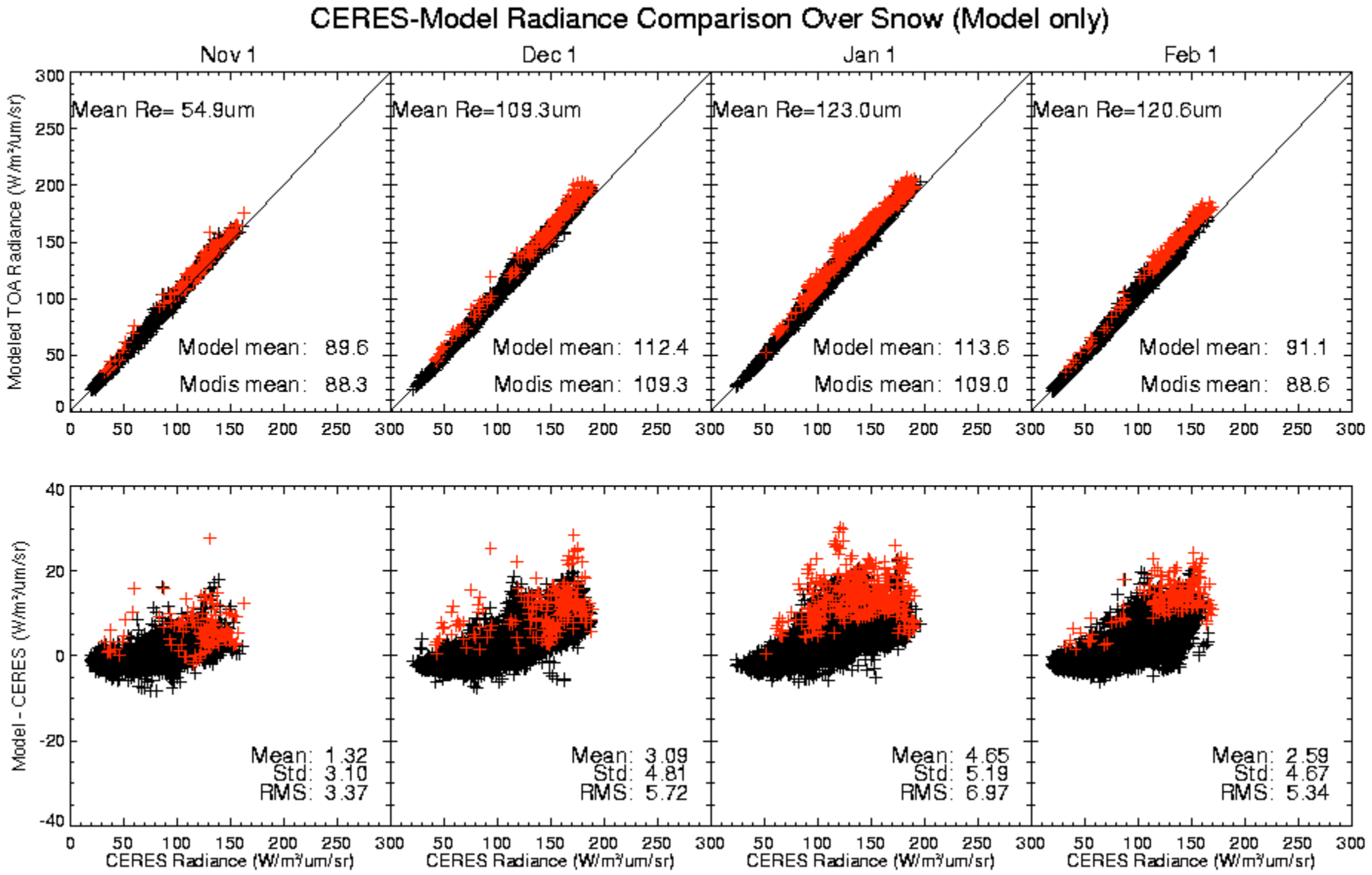
Data for the examples below are from Antarctic plateau, where water vapor and aerosol effects are small.

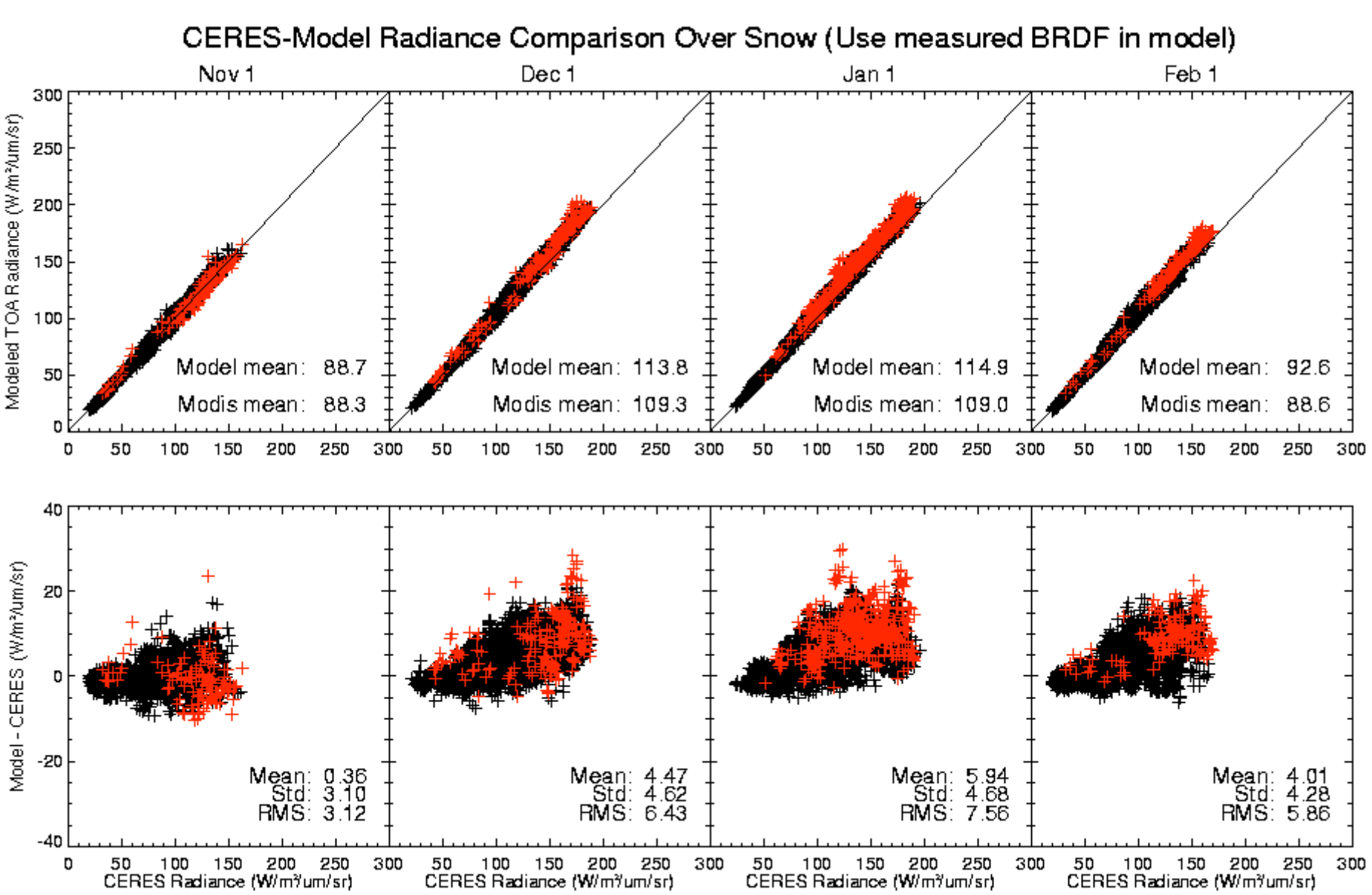

MODIS-Model Radiance Comparison Over Snow (0.64 um)
Nov 1
Dec 1
Jan 1
Feb 1
Mean Re= 54.9um
Mean Re=109.3um
Mean Re=123.0um
Mean Re=120.6um
Modeled TOA Radiance (W/m²/um/sr)
Model mean: 128.1
Modis mean: 131.3
Model mean: 167.8
Modis mean: 168.5
Model mean: 171.6
Modis mean: 170.0
Model mean: 136.8
Modis mean: 137.5
Model - MODIS (W/m²/um/sr)
Mean: -3.19
Std: 4.80
RMS: 5.76
Mean: -0.67
Std: 6.65
RMS: 6.68
Mean: 1.58
Std: 7.38
RMS: 7.54
Mean: -0.62
Std: 6.70
RMS: 6.73
MODIS Radiance (W/m²/um/sr)

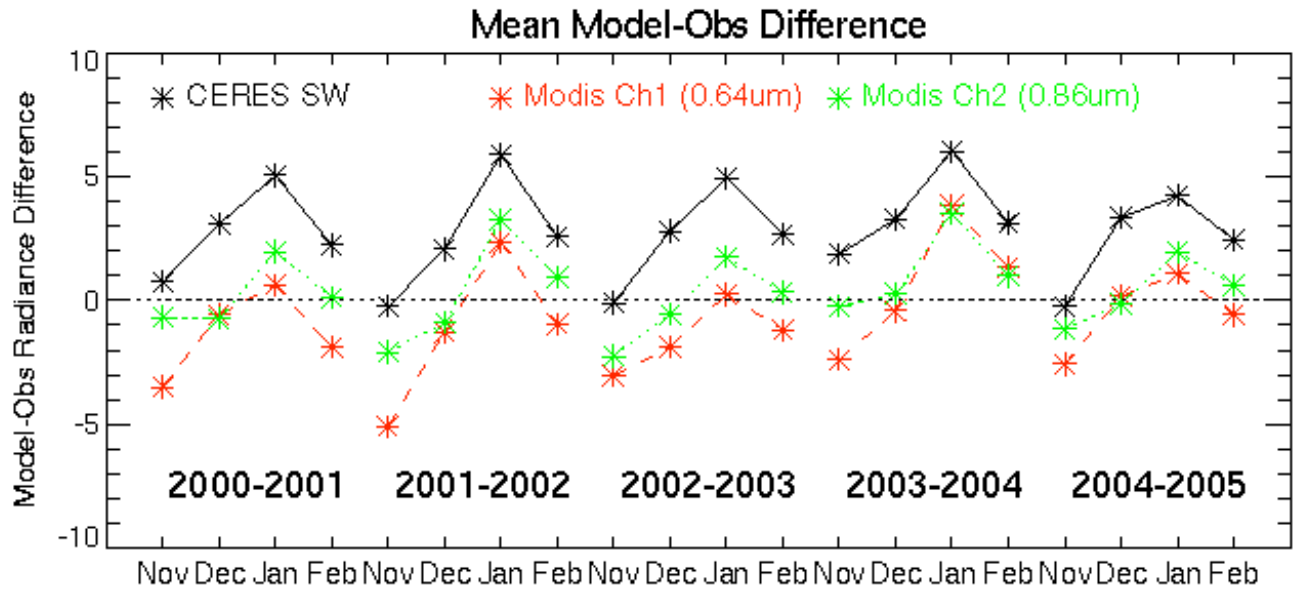

MODIS-Model Radiance Comparison Over Snow (0.64 um; use measured BRDF in model)
Nov 1
Dec 1
Jan 1
Feb 1
Modeled TOA Radiance (W/m²/um/sr)
Model mean: 130.6
Modis mean: 131.3
Model mean: 169.6
Modis mean: 168.5
Model mean: 172.5
Modis mean: 170.0
Model mean: 139.1
Modis mean: 137.5
Model - MODIS (W/m²/um/sr)
Mean: -0.70
Std: 5.16
RMS: 5.21
Mean: 1.13
Std: 5.42
RMS: 5.54
Mean: 2.54
Std: 5.32
RMS: 5.89
Mean: 1.61
Std: 4.92
RMS: 5.17
MODIS Radiance (W/m²/um/sr)

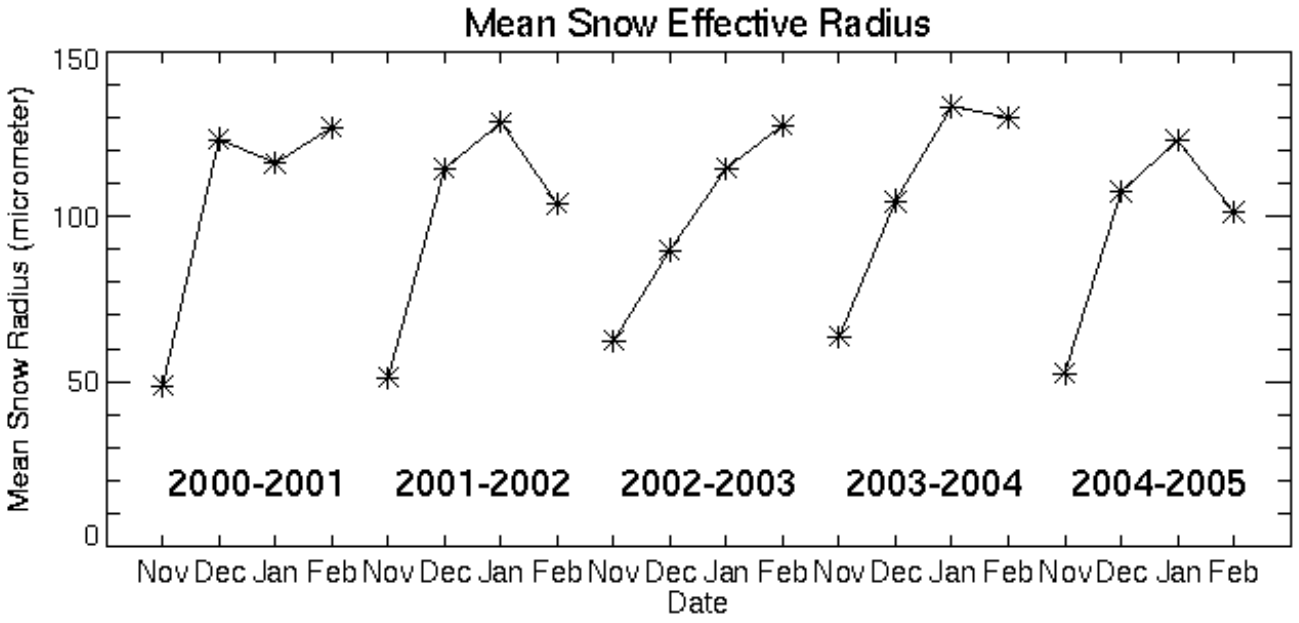

MODIS-Model Radiance Comparison Over Snow (0.86 um)
Nov 1
Dec 1
Jan 1
Feb 1
Mean Re= 54.9um
Mean Re=109.3um
Mean Re=123.0um
Mean Re=120.6um
Modeled TOA Radiance (W/m²/um/sr)
Model mean: 81.6
Modis mean: 82.8
Model mean: 104.5
Modis mean: 104.9
Model mean: 107.1
Modis mean: 104.6
Model mean: 85.8
Modis mean: 85.2
Model - MODIS (W/m²/um/sr)
Mean: -1.19
Std: 3.01
RMS: 3.23
Mean: -0.38
Std: 4.60
RMS: 4.62
Mean: 2.48
Std: 5.41
RMS: 5.95
Mean: 0.58
Std: 4.88
RMS: 4.92
MODIS Radiance (W/m²/um/sr)


MODIS-Model Radiance Comparison Over Snow (0.86 um; use measured BRDF in model)
Nov 1
Dec 1
Jan 1
Feb 1
Modeled TOA Radiance (W/m²/um/sr)
Model mean: 81.9
Modis mean: 82.8
Model mean: 105.7
Modis mean: 104.9
Model mean: 107.9
Modis mean: 104.6
Model mean: 87.1
Modis mean: 85.2
Model - MODIS (W/m²/um/sr)
Mean: -0.88
Std: 3.14
RMS: 3.26
Mean: 0.87
Std: 4.01
RMS: 4.10
Mean: 3.26
Std: 4.30
RMS: 5.40
Mean: 1.88
Std: 3.84
RMS: 4.27
MODIS Radiance (W/m²/um/sr)


CERES-Model Radiance Comparison Over Snow (Model only)
Nov 1
Dec 1
Jan 1
Feb 1
Mean Re= 54.9um
Mean Re=109.3um
Mean Re=123.0um
Mean Re=120.6um
Modeled TOA Radiance (W/m²/um/sr)
Model mean: 89.6
Modis mean: 88.3
Model mean: 112.4
Modis mean: 109.3
Model mean: 113.6
Modis mean: 109.0
Model mean: 91.1
Modis mean: 88.6
Model - CERES (W/m²/um/sr)
Mean: 1.32
Std: 3.10
RMS: 3.37
Mean: 3.09
Std: 4.81
RMS: 5.72
Mean: 4.65
Std: 5.19
RMS: 6.97
Mean: 2.59
Std: 4.67
RMS: 5.34
CERES Radiance (W/m²/um/sr)


CERES-Model Radiance Comparison Over Snow (Use measured BRDF in model)
Nov 1
Dec 1
Jan 1
Feb 1
Modeled TOA Radiance (W/m²/um/sr)
Model mean: 88.7
Modis mean: 88.3
Model mean: 113.8
Modis mean: 109.3
Model mean: 114.9
Modis mean: 109.0
Model mean: 92.6
Modis mean: 88.6
Model - CERES (W/m²/um/sr)
Mean: 0.36
Std: 3.10
RMS: 3.12
Mean: 4.47
Std: 4.62
RMS: 6.43
Mean: 5.94
Std: 4.68
RMS: 7.56
Mean: 4.01
Std: 4.28
RMS: 5.86
CERES Radiance (W/m²/um/sr)

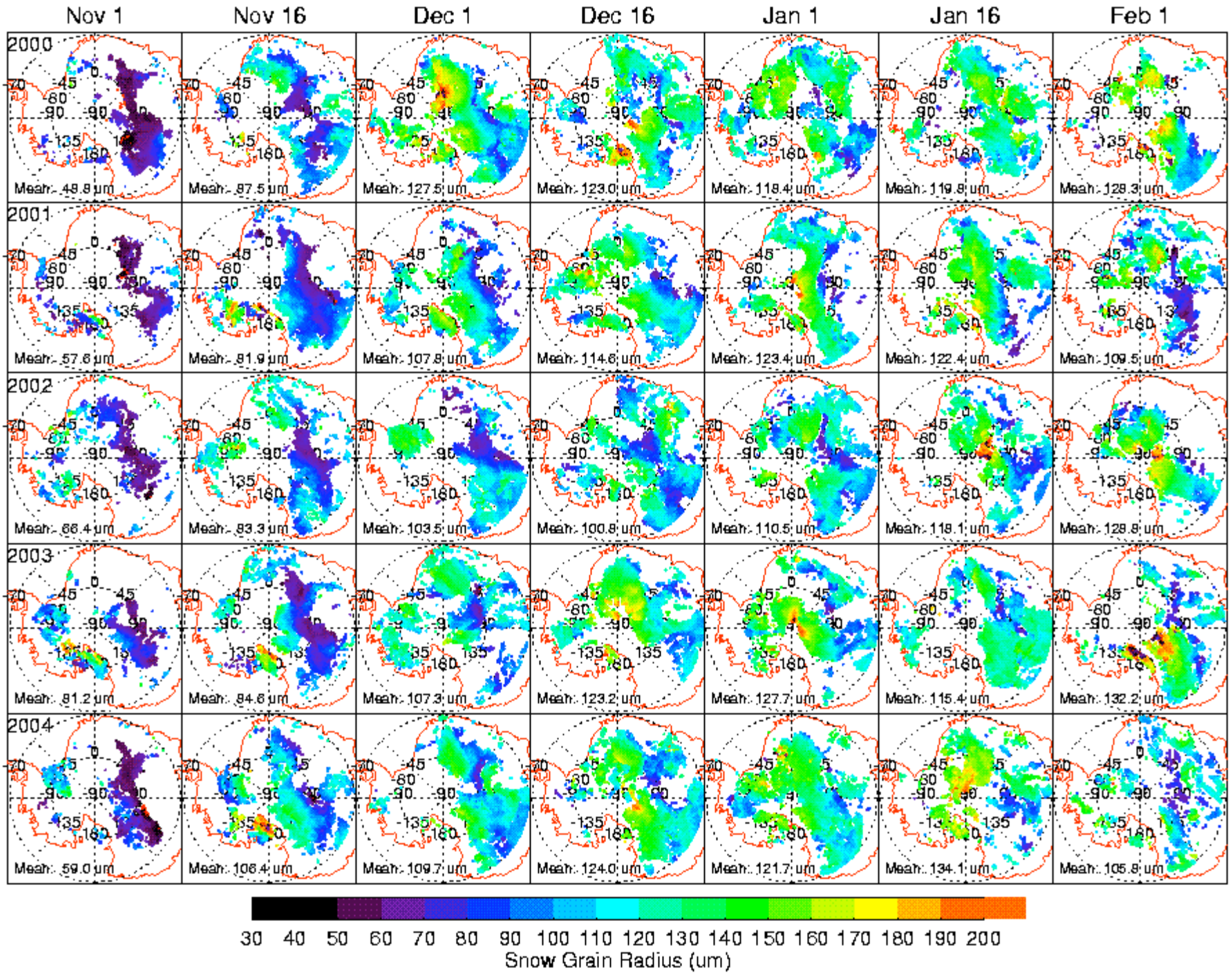

Mean Model-Obs Difference
CERES SW
Modis Ch1 (0.64um)
Modis Ch2 (0.86um)
Model-Obs Radiance Difference
10
5
0
-5
-10
2000-2001
2001-2002
2002-2003
2003-2004
2004-2005
Nov Dec Jan Feb Nov Dec Jan Feb Nov Dec Jan Feb Nov Dec Jan Feb Nov Dec Jan Feb

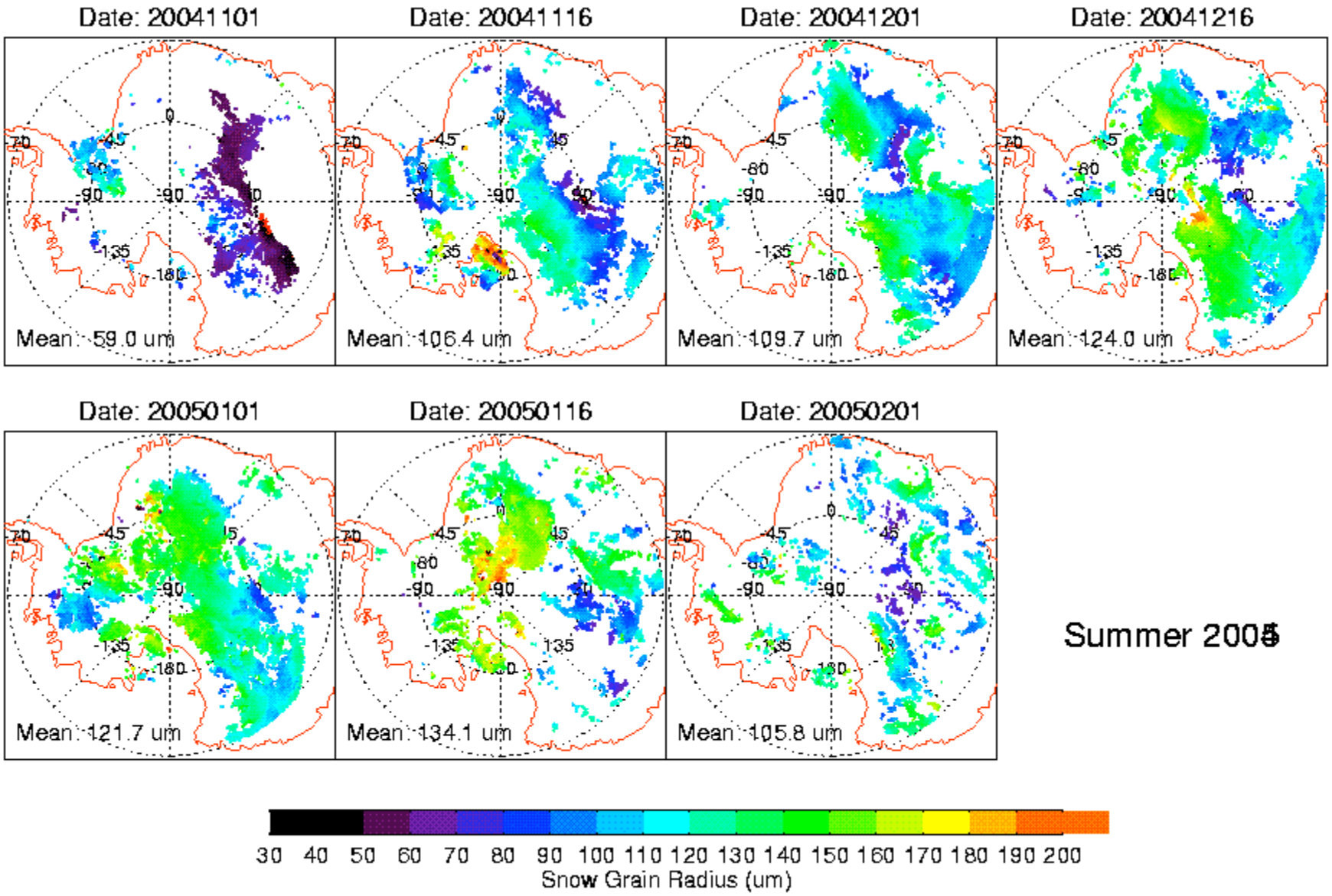

Mean Snow Effective Radius
Mean Snow Radius (micrometer)
150
100
50
0
2000-2001
2001-2002
2002-2003
2003-2004
2004-2005
Nov Dec Jan Feb Nov Dec Jan Feb Nov Dec Jan Feb Nov Dec Jan Feb Nov Dec Jan Feb
Date

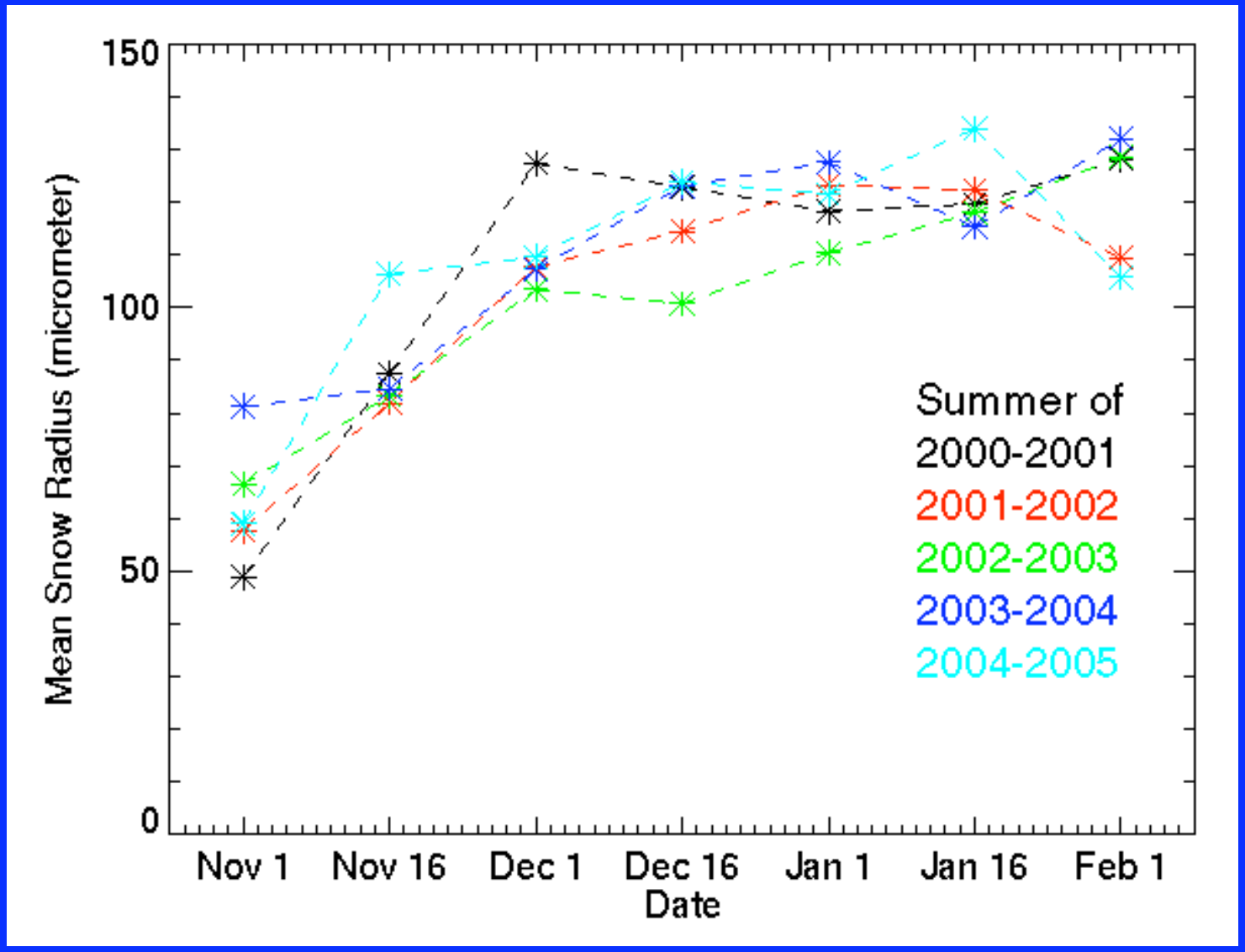
4. Snow Grain Size Retrieval for CERES SRAB

Snow grain size (*Re*) determines the spectral albedo and albedo shape.

Using grain size retrieved from MODIS data and a two-layer snow model will provide a more accurate spectral surface albedo for the next version of CERES SARB.


Nov 1
Nov 16
Dec 1
Dec 16
Jan 1
Jan 16
Feb 1
2000
Mean: 48.8 um
Mean: 87.5 um
Mean: 127.5 um
Mean: 123.0 um
Mean: 118.4 um
Mean: 119.8 um
Mean: 128.3 um
2001
Mean: 57.6 um
Mean: 81.9 um
Mean: 107.8 um
Mean: 114.6 um
Mean: 123.4 um
Mean: 122.4 um
Mean: 109.5 um
2002
Mean: 66.4 um
Mean: 83.3 um
Mean: 103.5 um
Mean: 100.8 um
Mean: 110.5 um
Mean: 118.1 um
Mean: 128.8 um
2003
Mean: 81.2 um
Mean: 84.6 um
Mean: 107.3 um
Mean: 123.2 um
Mean: 127.7 um
Mean: 115.4 um
Mean: 132.2 um
2004
Mean: 59.0 um
Mean: 106.4 um
Mean: 109.7 um
Mean: 124.0 um
Mean: 121.7 um
Mean: 134.1 um
Mean: 105.8 um
30 40 50 60 70 80 90 100 110 120 130 140 150 160 170 180 190 200
Snow Grain Radius (um)


Date: 20041101
Date: 20041116
Date: 20041201
Date: 20041216
Mean: 59.0 um
Mean: 106.4 um
Mean: 109.7 um
Mean: 124.0 um
Date: 20050101
Date: 20050116
Date: 20050201
Mean: 121.7 um
Mean: 134.1 um
Mean: 105.8 um
Summer 2005
30 40 50 60 70 80 90 100 110 120 130 140 150 160 170 180 190 200
Snow Grain Radius (um)


150
100
50
0
Mean Snow Radius (micrometer)
Nov 1
Nov 16
Dec 1
Dec 16
Jan 1
Jan 16
Feb 1
Date
Summer of
2000-2001
2001-2002
2002-2003
2003-2004
2004-2005

Summary

- New set of snow optical properties are created and tested, and are implemented in the radiative transfer model.
- Except for some extreme view geometries, the model-observation radiance comparisons show good agreement.
- Results suggest that a two layer snow model need to be applied in the next version of CERES SARB retrieval to have a correct spectral shape of snow albedo.
- The spectral shape is mainly determined by the top layer of snow grain size, which can be retrieved through MODIS reflectances.
- The results suggest that the observations from those extreme large view angles should be avoided for grain size retrieval.
- Initial results of the grain size retrieval are promising, but further check on pass by pass consistence is required.

Acknowledgments:

We thank Dr. Stephen Warren's group at University of Washington for the snow surface measurement data; NASA Langley DAAC for CERES/MODIS data; and Grant Matthews for the updated CERES calibration.