Progress Report of Snow Angular Distribution Model

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Objectives

(1) Understand characteristics of radiance reflected by snow covered surfaces.
(2) Separate scene types using imager to reduce the error in flux derived by ADMs.

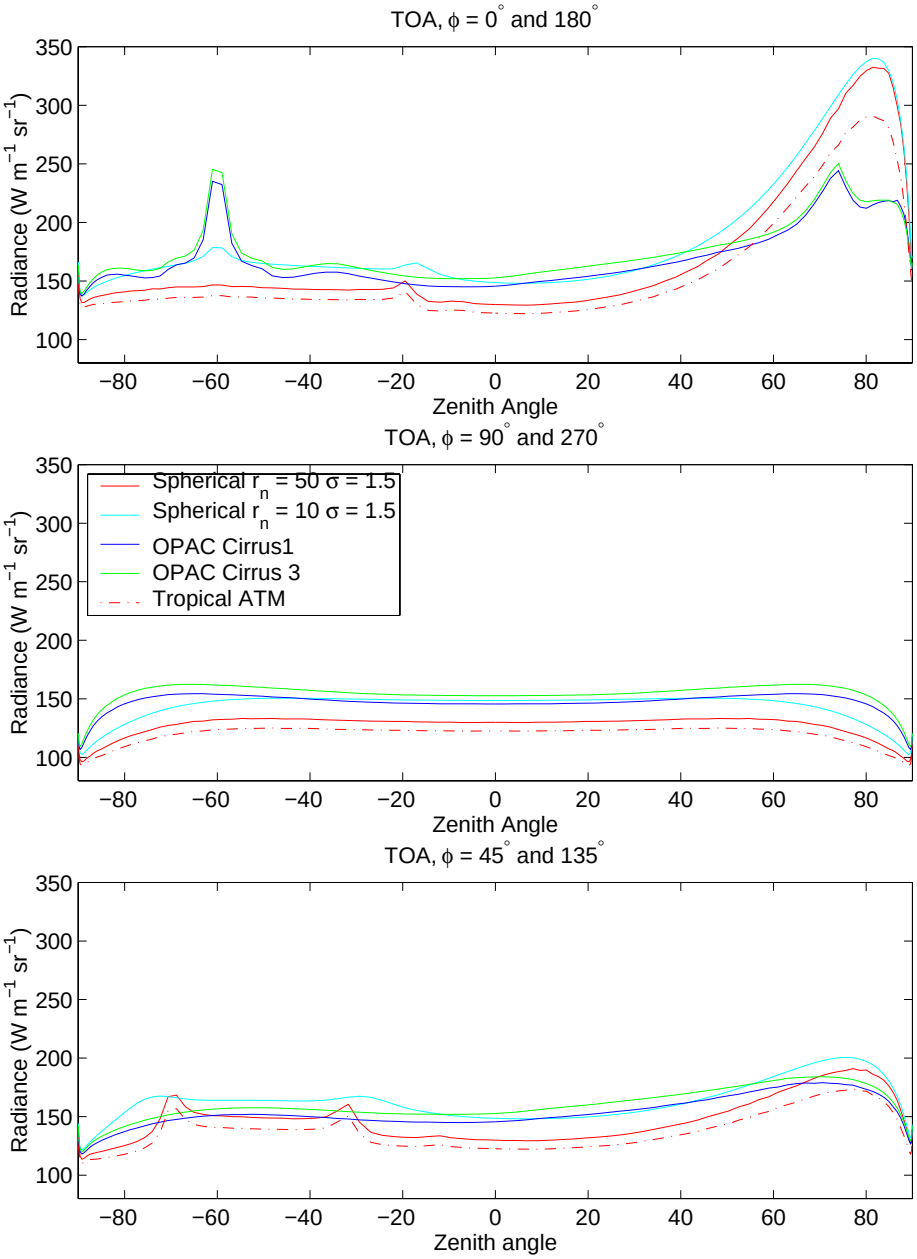
Normalized Difference Snow Index (NDSI)

Klein et al. (2002) use Normalized Difference Snow Index (NDSI) to detect snow covered surface from satellites. Similar to NDSI defined by Klein et al. we define NDSI by

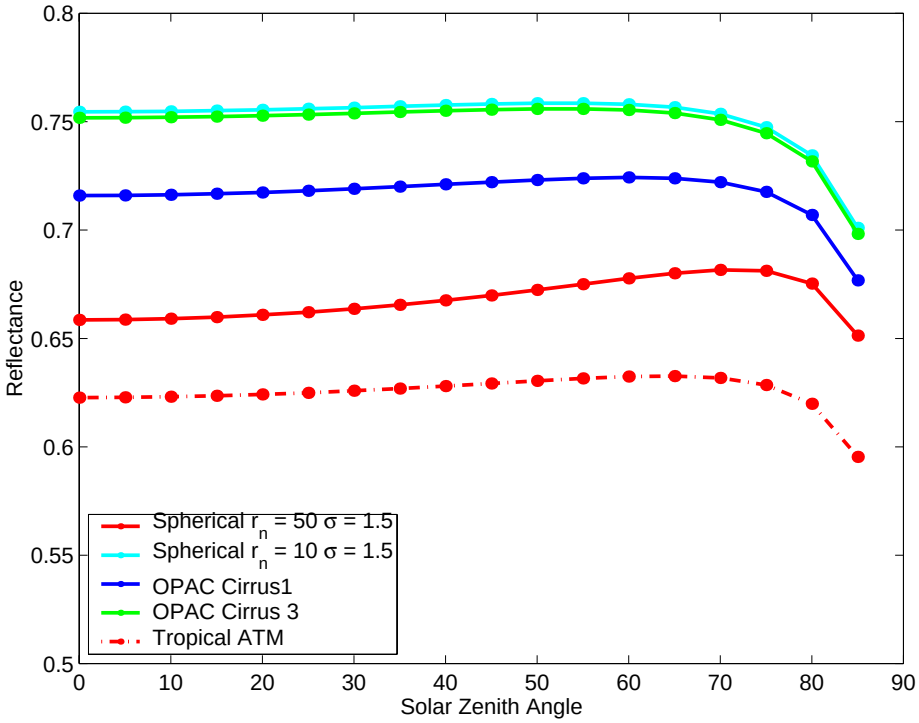
$$NDSI = \frac{r_1 - r_2}{r_1 + r_2}, \tag{1}$$

where r_1 is the reflectivity of the surface at 0.646 μm (Klein et al. use 0.55 μm) and r_2 is the reflectivity of the surface at 1.6 μm.

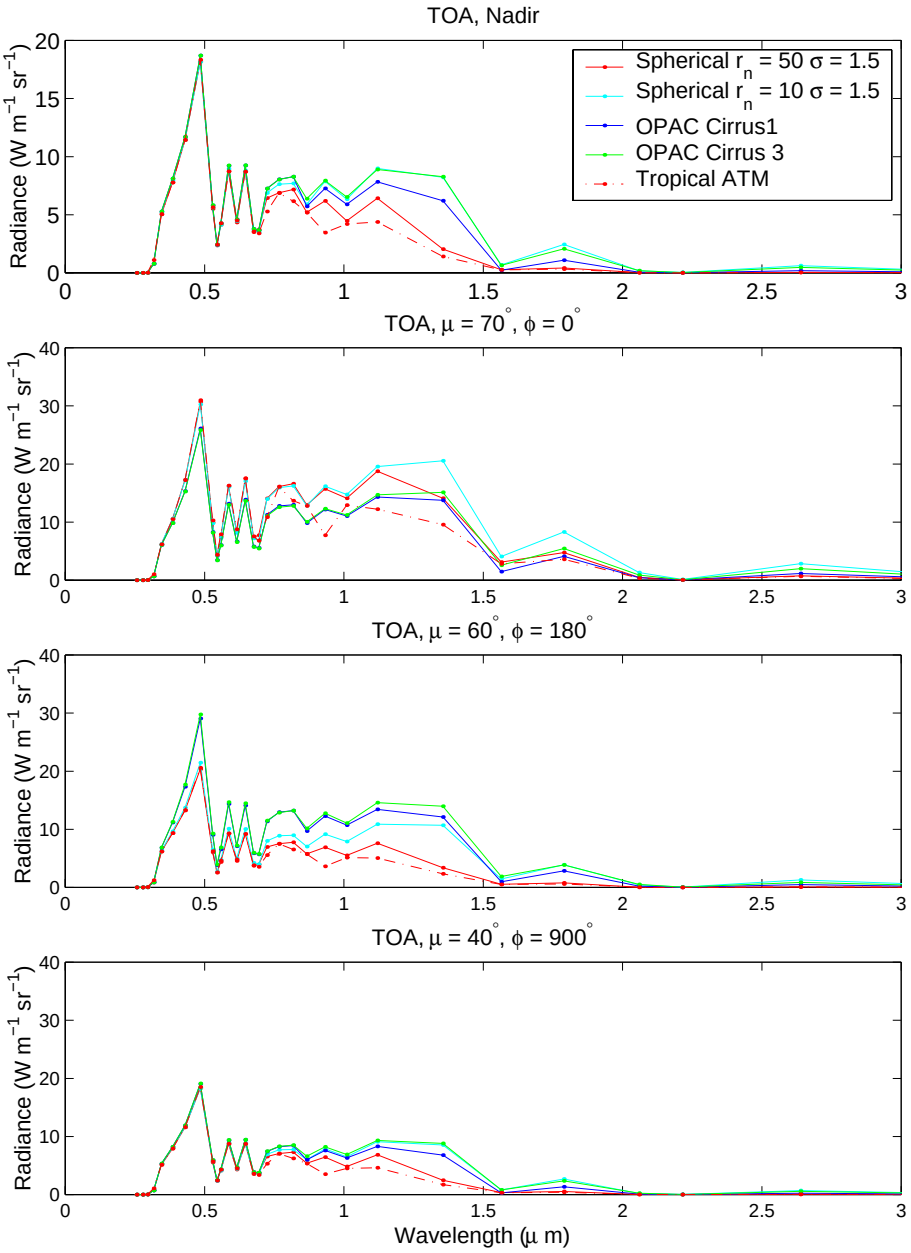
Klein, A. G. D. K. Hall, and G. A. Riggs, 2002: Improving snow-cover mapping in forests through the use of a canopy reflectance model, Submitted to *Hydrological Process.*



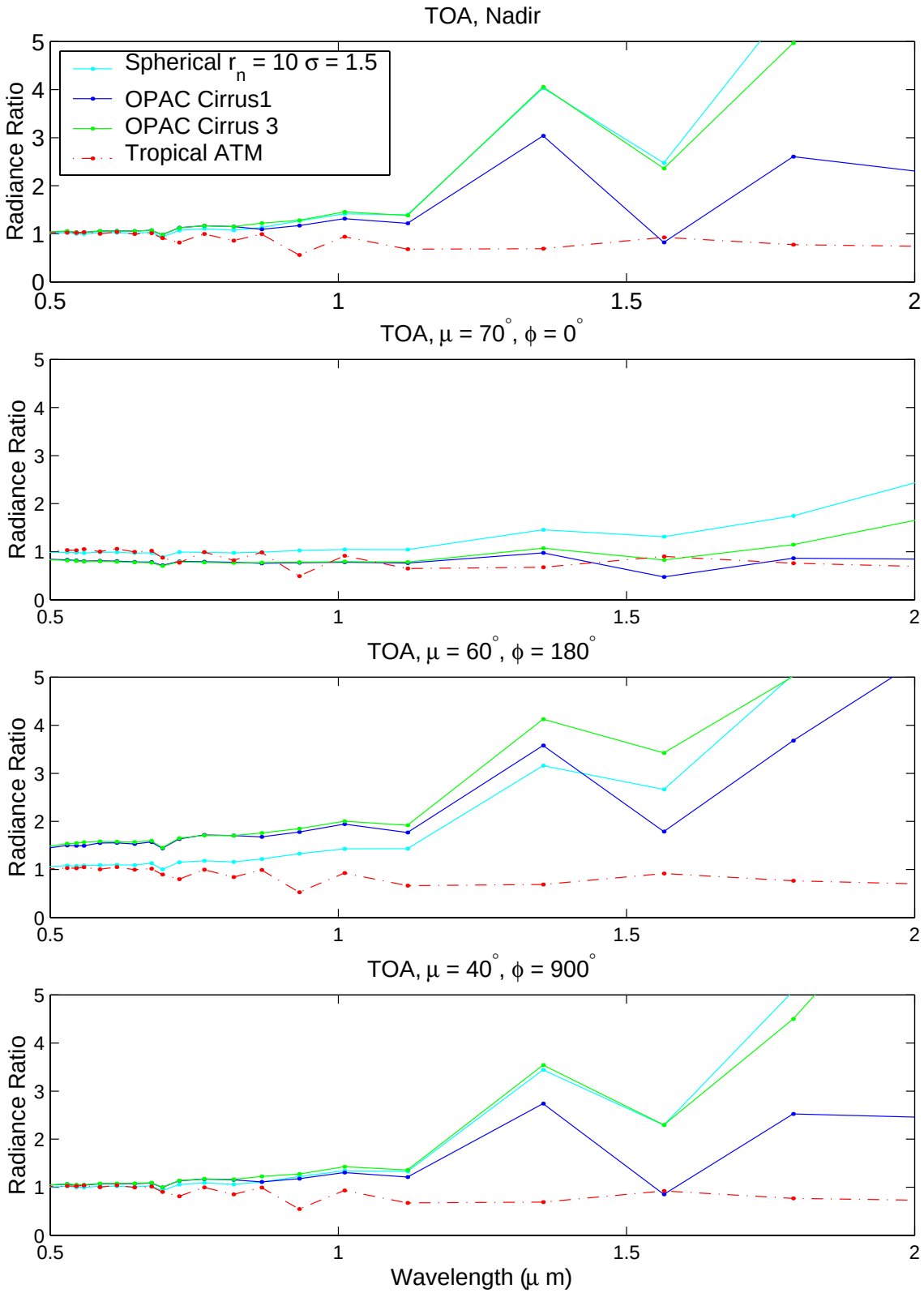
Radiance as a function of viewing zenith angles for different sizes and shapes of ice particles. The solar zenith angle is 60°. The subarctic winter standard atmosphere was used for the computation. The positive viewing zenith angle is looking toward the position of the sun. Spherical particles have larger radiances at the positive viewing angle than non spherical particles. When the size of particles increases, radiance reduces at all angles. Photons scattered more forward direction as particle size increases. Therefore, the mean path of photons reflected by optically thick layer composed by weakly absorbing particles increases as the particle size increases. For the comparison, the tropical atmosphere was also used to compute radiances for spherical particles with the mode radius of 50 μm. The difference is noticeable but somewhat smaller than that is causes by the difference of particle shapes.



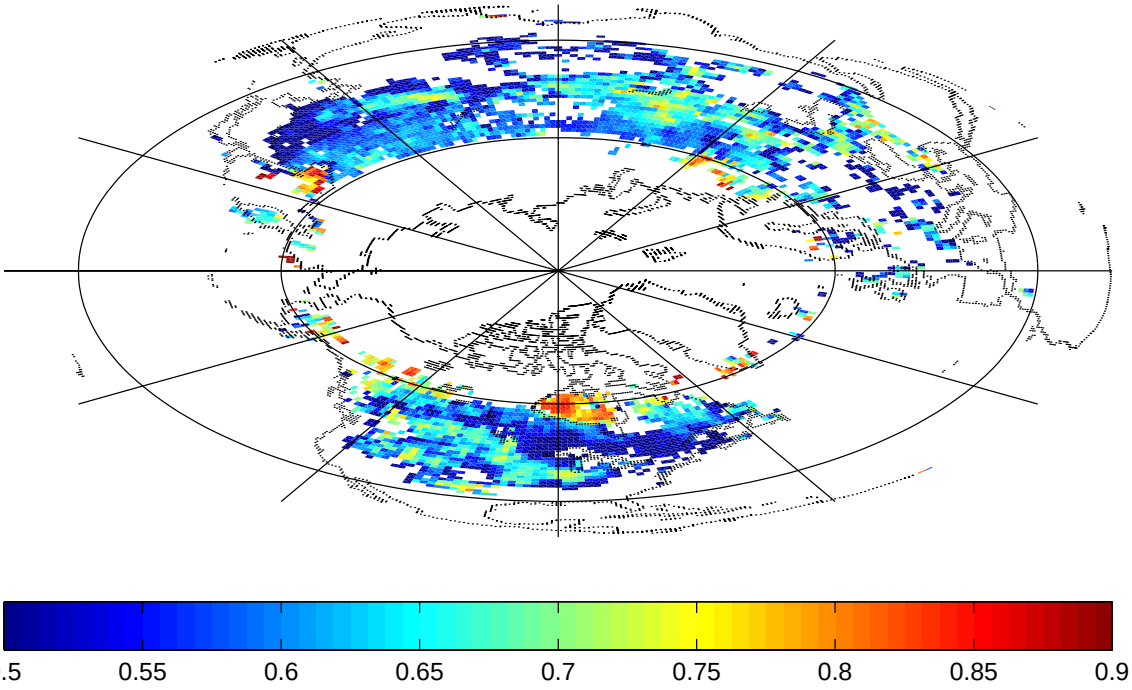
Reflectivity as a function of solar zenith angle for different type of snow surfaces. The subarctic winter standard atmosphere was used for the computation except for one labeled as tropical atmosphere. The reflectivity depends on particle size and shape as well as atmospheric condition. However it does not depend on the solar zenith angle very much.



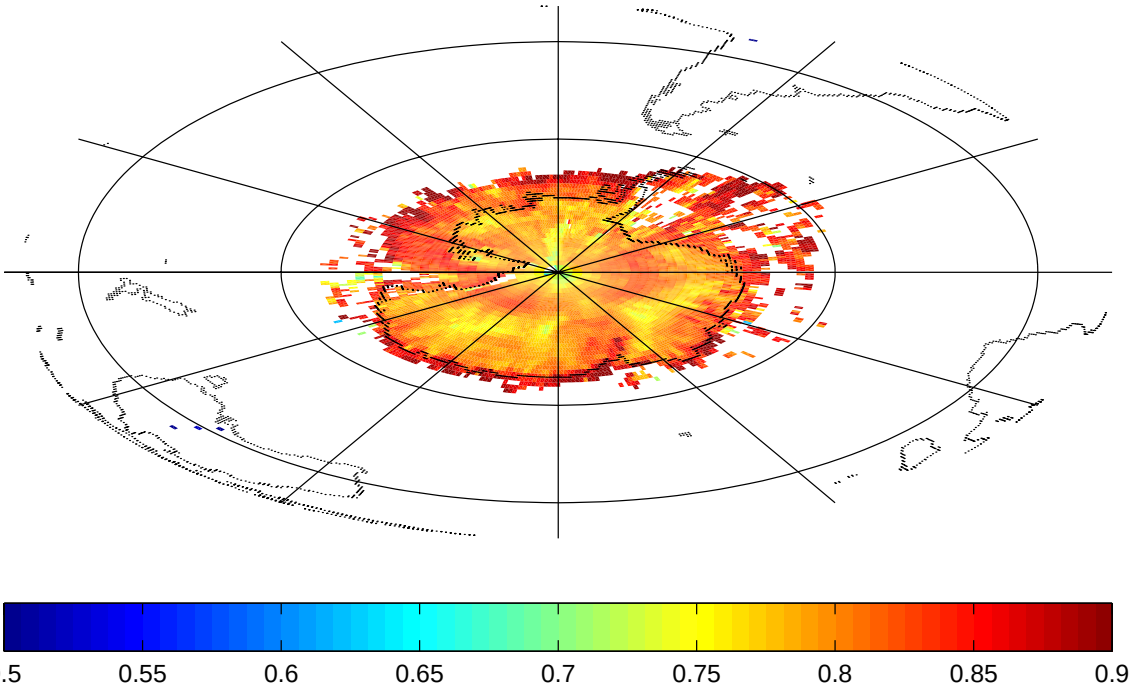
Radiances at different viewing geometry as a function of wavelength. The solar zenith angle is 60°. MODIS three channels are at 630 nm, 830 nm, and 1.6 μm. Radiances in these channels are weakly affected by changing water vapor amount. Radiances at 1.6 μm is larger with small ice particles than large particles. Therefore, NDSI is larger for large particles than smaller particles.


TOA, Nadir
Spherical r_n = 10 σ = 1.5
OPAC Cirrus1
OPAC Cirrus 3
Tropical ATM
Radiance Ratio
TOA, μ = 70°, ϕ = 0°
TOA, μ = 60°, ϕ = 180°
TOA, μ = 40°, ϕ = 900°
Wavelength (μ m)

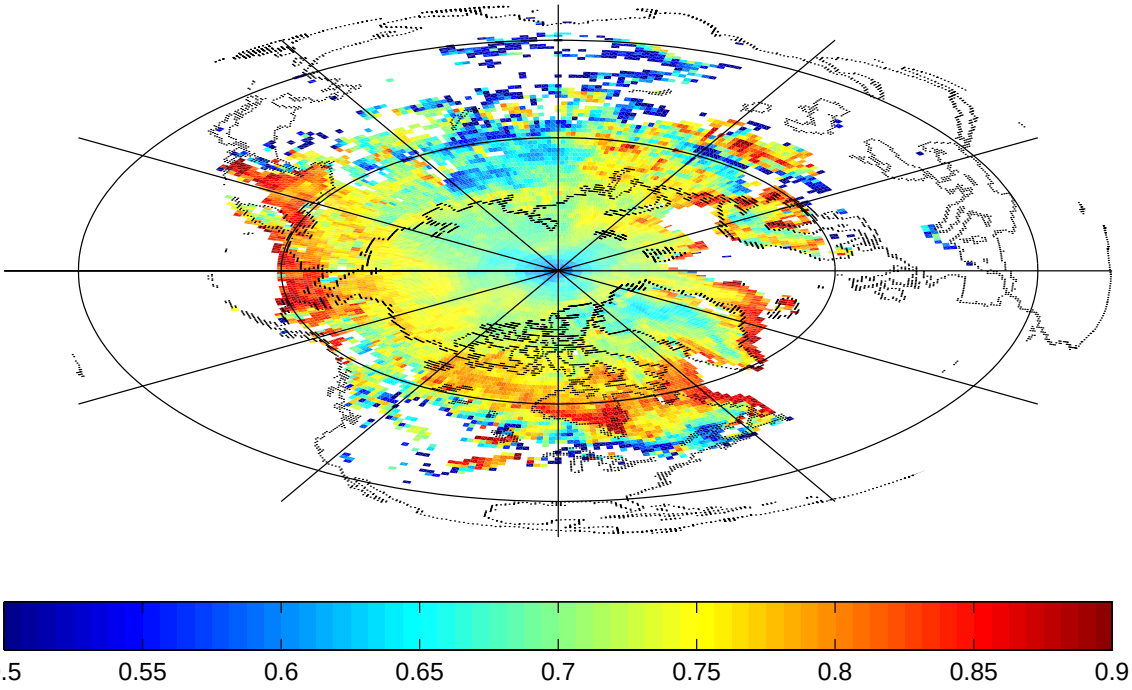
NDSI, Dec. 2000



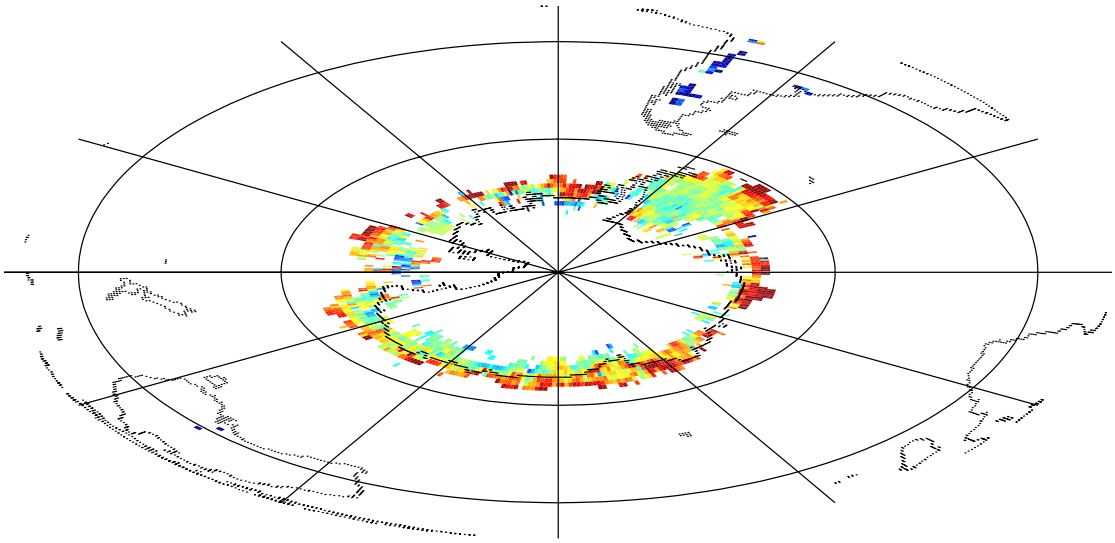
NDSI, Dec. 2000

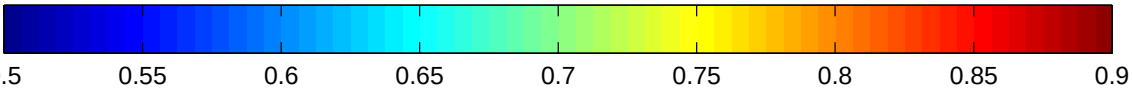


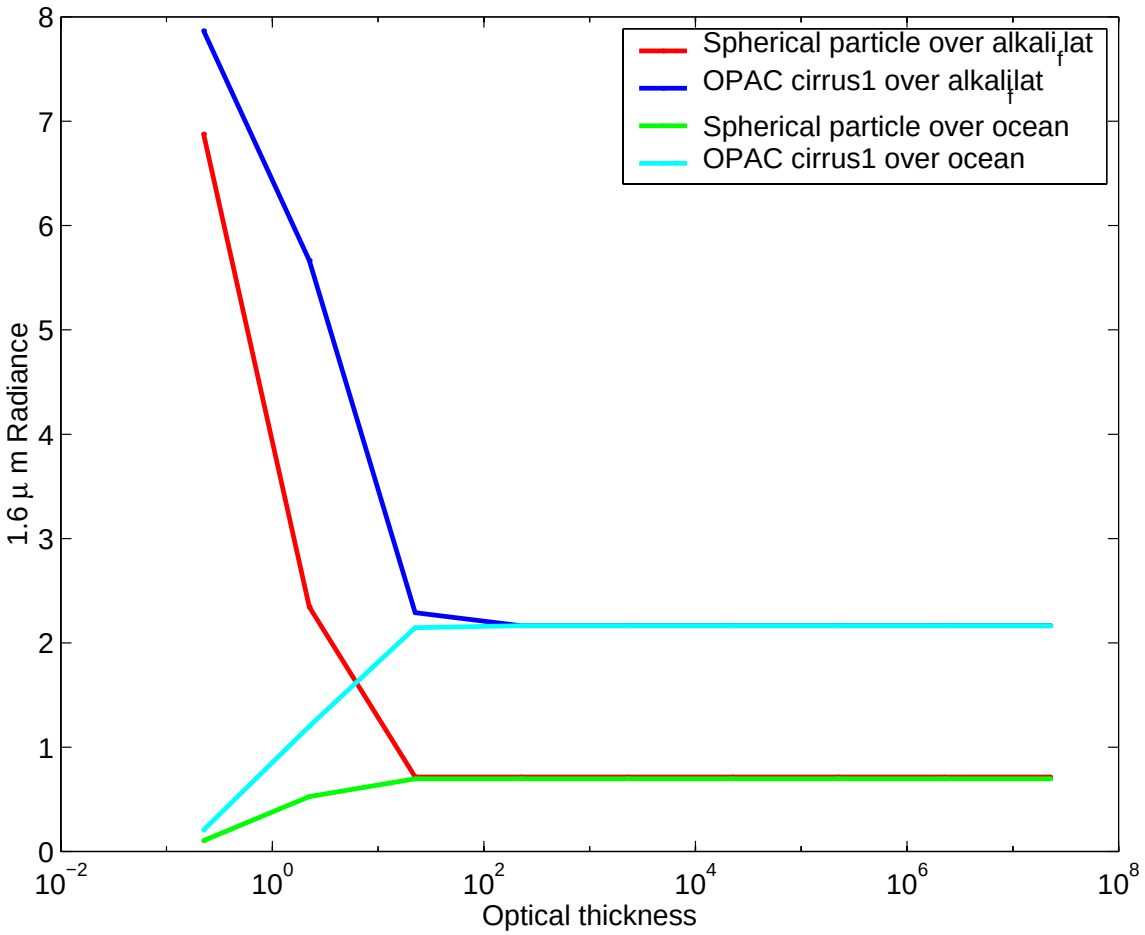
NDSI, April 2001

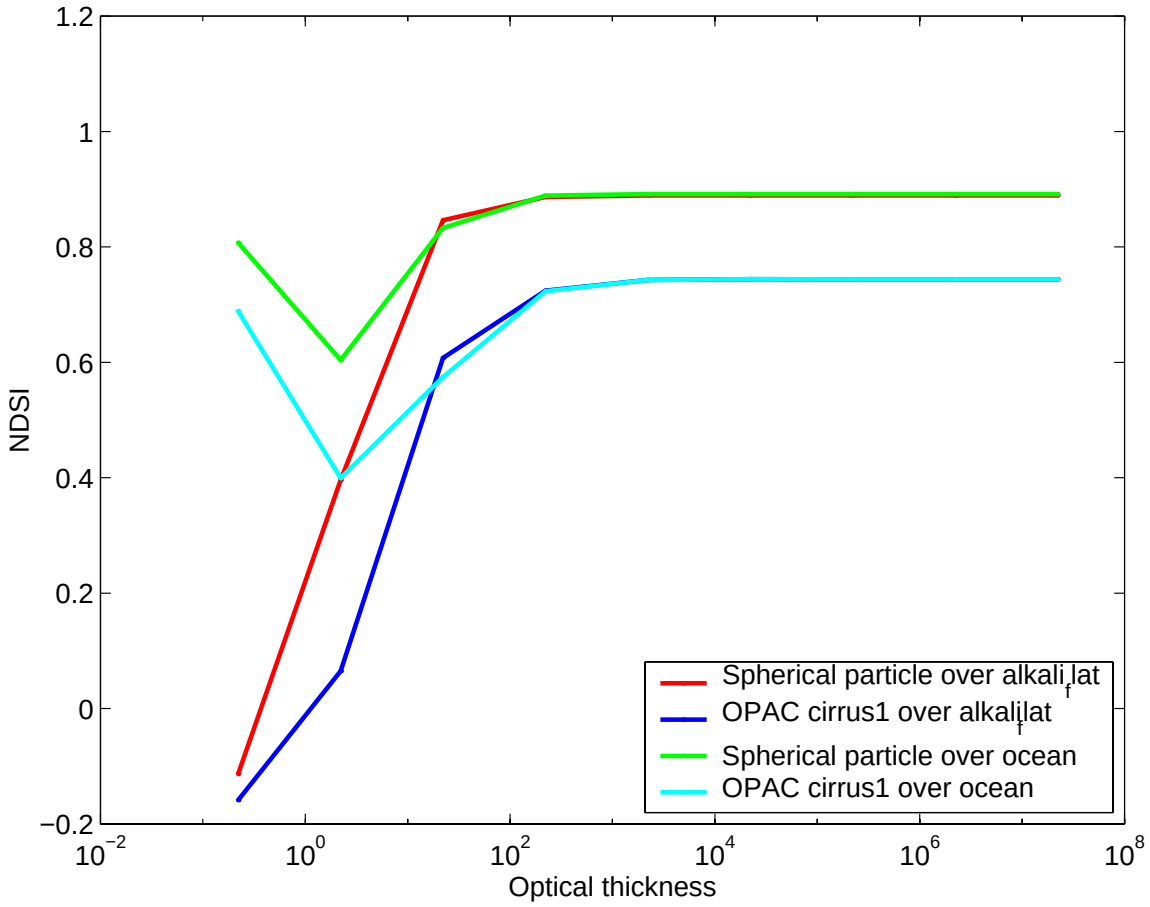


NDSI, April 2001

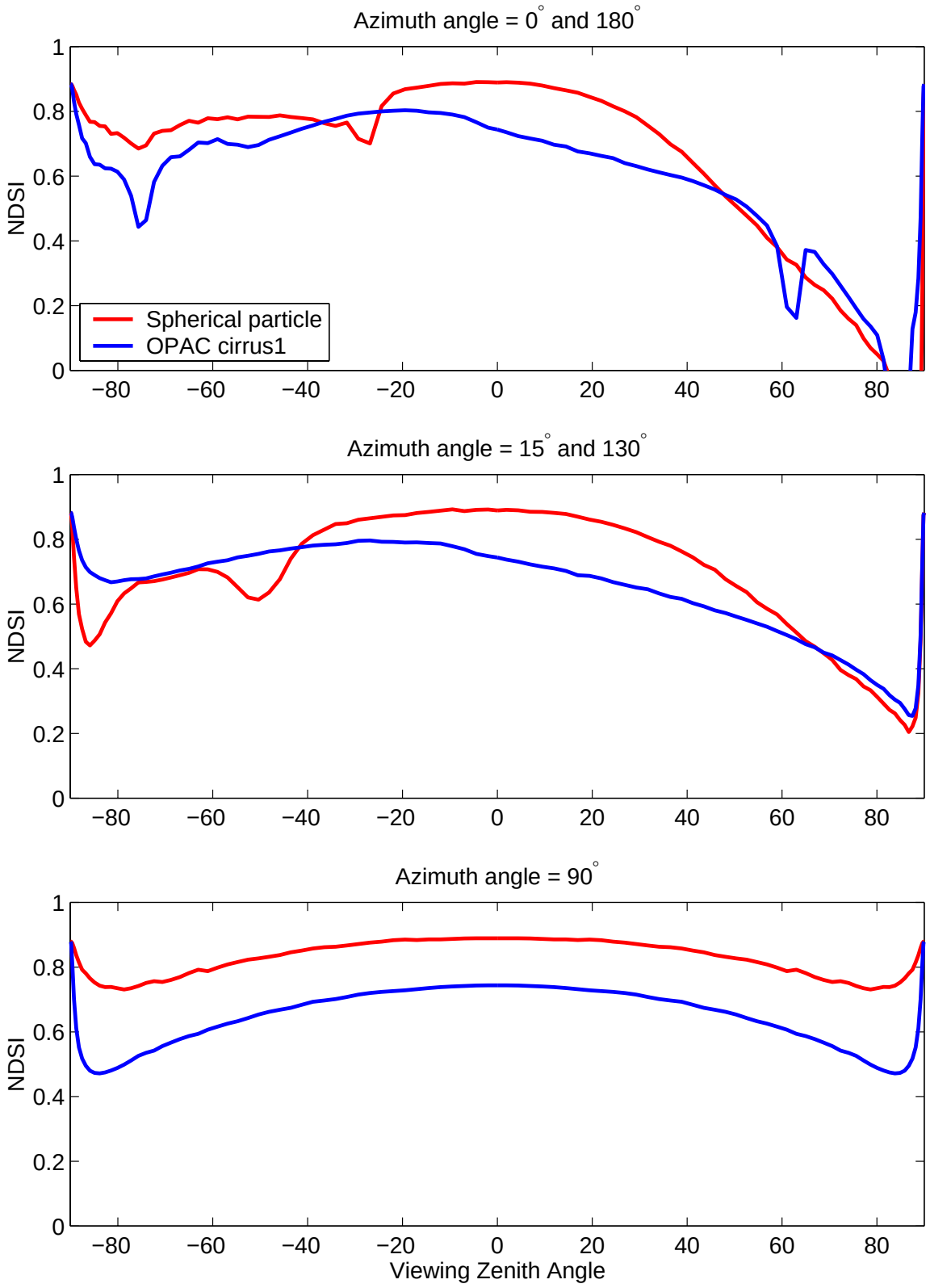


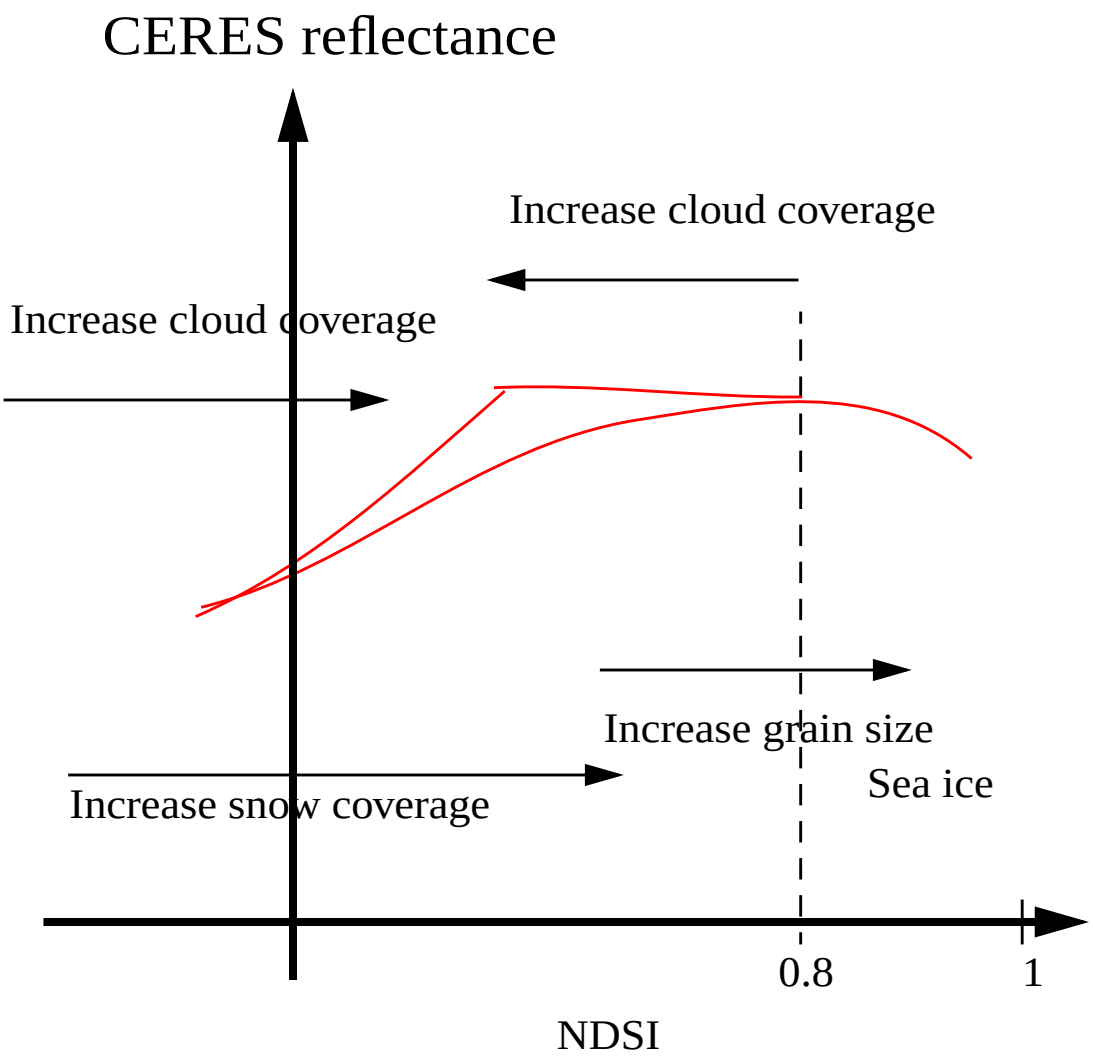


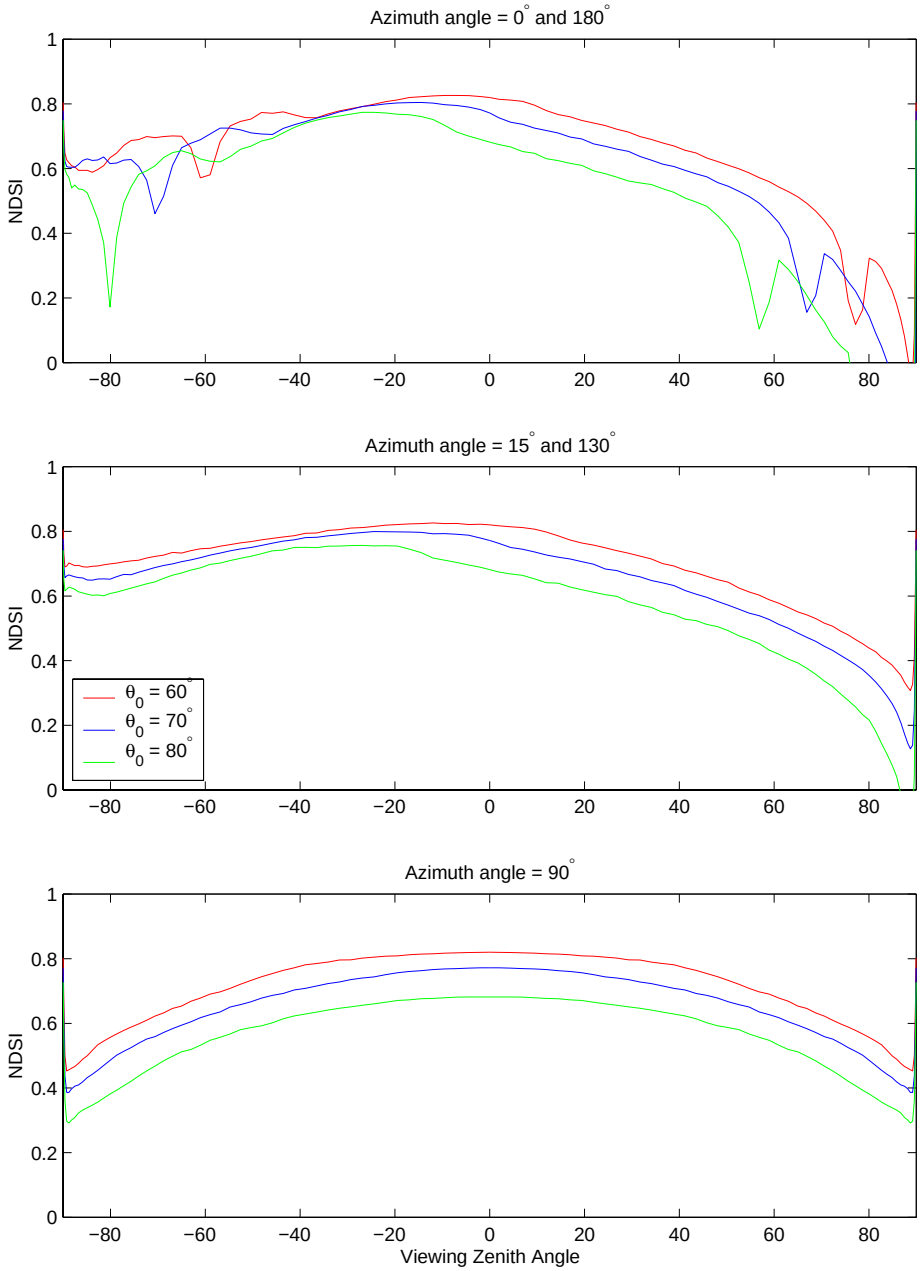

Spherical particle over alkali lat f
OPAC cirrus1 over alkali lat f
Spherical particle over ocean
OPAC cirrus1 over ocean
1.6 μ m Radiance
Optical thickness
0
1
2
3
4
5
6
7
8
10^-2
10^0
10^2
10^4
10^6
10^8



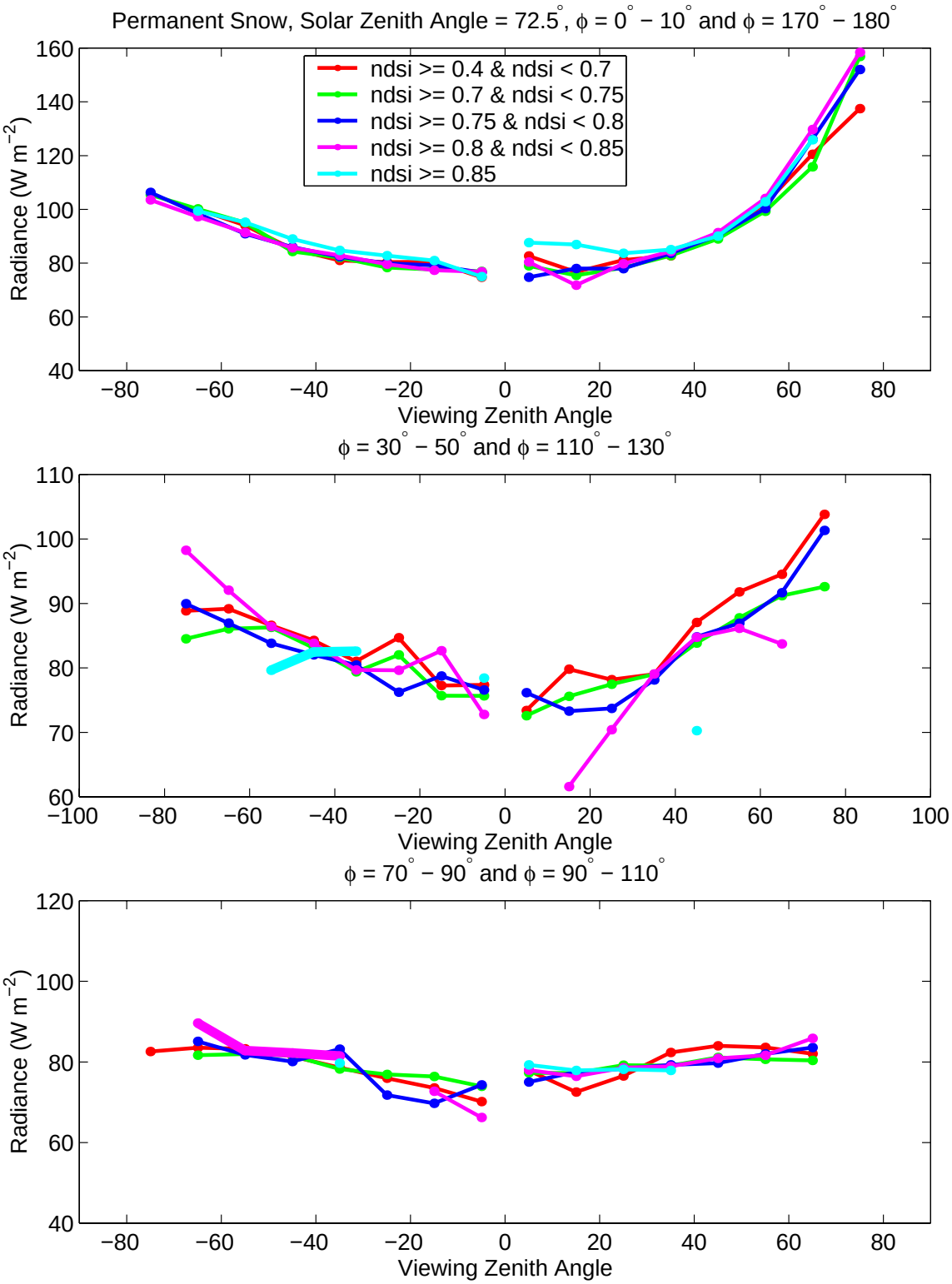
NDSI at nadir.

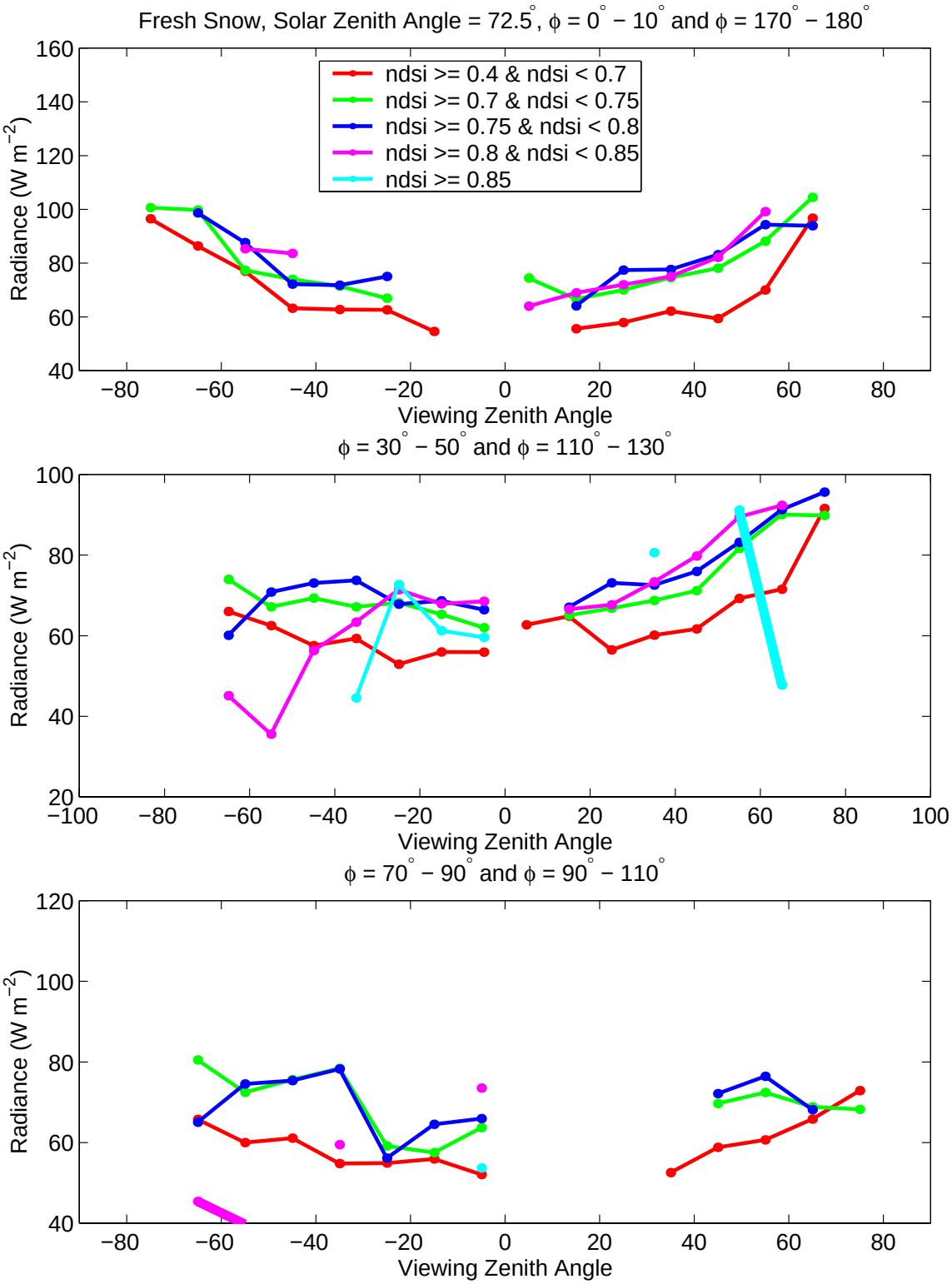

Azimuth angle = 0° and 180°
NDSI
Spherical particle
OPAC cirrus1
Azimuth angle = 15° and 130°
NDSI
Azimuth angle = 90°
NDSI
Viewing Zenith Angle

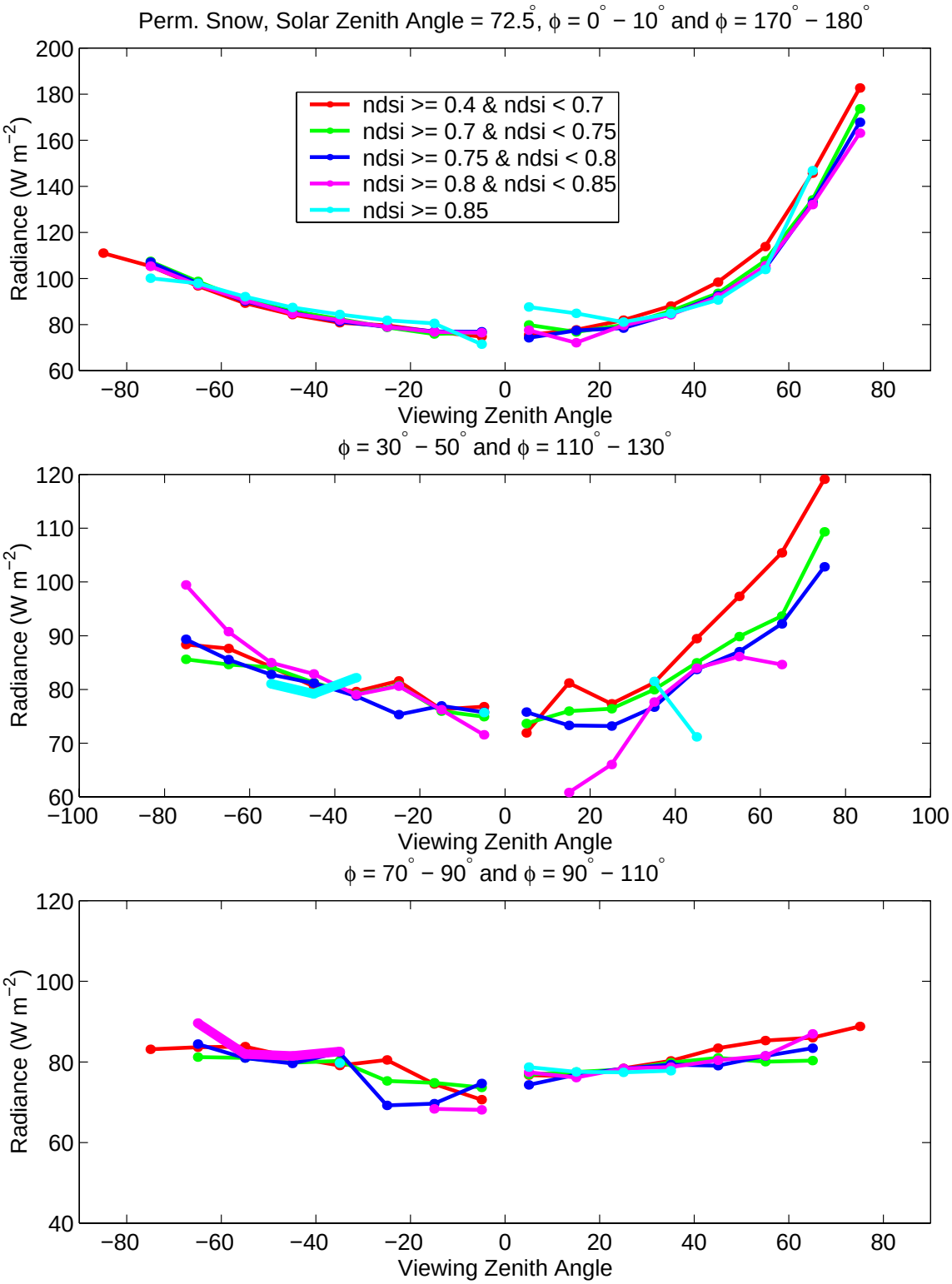

CERES reflectance
Increase cloud coverage
Increase cloud coverage
Increase grain size
Sea ice
Increase snow coverage
0.8
1
NDSI

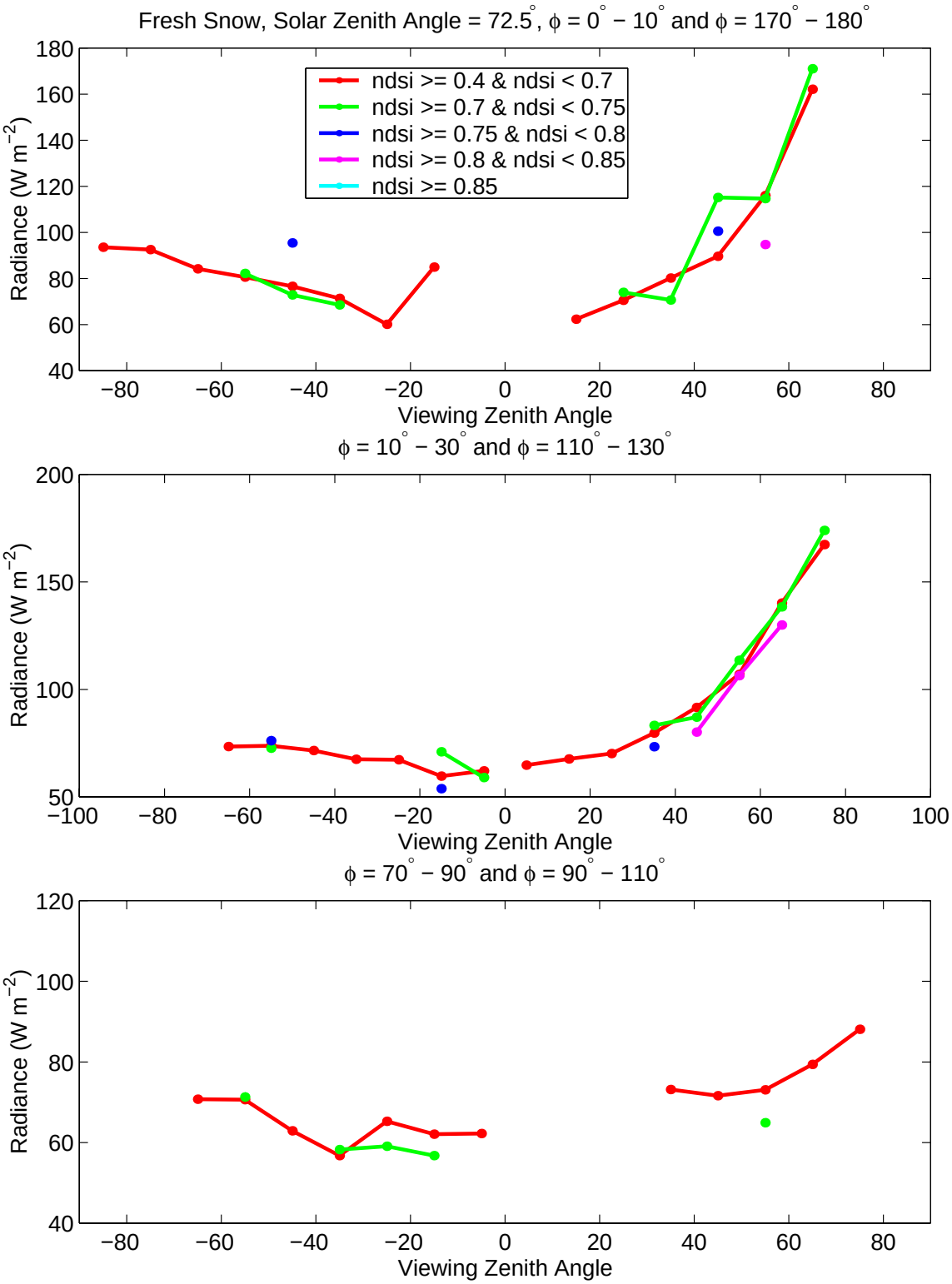


NDSI as a function of viewing zenith angle at various different viewing azimuth angles for different solar zenith angles. NDSI decreases with increasing solar zenith angle, which is consistent with observations.


Permanent Snow, Solar Zenith Angle = 72.5°, ϕ = 0° − 10° and ϕ = 170° − 180°
ndsi >= 0.4 & ndsi < 0.7
ndsi >= 0.7 & ndsi < 0.75
ndsi >= 0.75 & ndsi < 0.8
ndsi >= 0.8 & ndsi < 0.85
ndsi >= 0.85
Radiance (W m−2)
Viewing Zenith Angle
ϕ = 30° − 50° and ϕ = 110° − 130°
Radiance (W m−2)
Viewing Zenith Angle
ϕ = 70° − 90° and ϕ = 90° − 110°
Radiance (W m−2)
Viewing Zenith Angle


Fresh Snow, Solar Zenith Angle = 72.5°, ϕ = 0° − 10° and ϕ = 170° − 180°
ndsi >= 0.4 & ndsi < 0.7
ndsi >= 0.7 & ndsi < 0.75
ndsi >= 0.75 & ndsi < 0.8
ndsi >= 0.8 & ndsi < 0.85
ndsi >= 0.85
Radiance (W m−2)
Viewing Zenith Angle
ϕ = 30° − 50° and ϕ = 110° − 130°
Radiance (W m−2)
Viewing Zenith Angle
ϕ = 70° − 90° and ϕ = 90° − 110°
Radiance (W m−2)
Viewing Zenith Angle


Perm. Snow, Solar Zenith Angle = 72.5°, ϕ = 0° − 10° and ϕ = 170° − 180°
ndsi >= 0.4 & ndsi < 0.7
ndsi >= 0.7 & ndsi < 0.75
ndsi >= 0.75 & ndsi < 0.8
ndsi >= 0.8 & ndsi < 0.85
ndsi >= 0.85
Radiance (W m−2)
Viewing Zenith Angle
ϕ = 30° − 50° and ϕ = 110° − 130°
Radiance (W m−2)
Viewing Zenith Angle
ϕ = 70° − 90° and ϕ = 90° − 110°
Radiance (W m−2)
Viewing Zenith Angle


Fresh Snow, Solar Zenith Angle = 72.5°, ϕ = 0° − 10° and ϕ = 170° − 180°
ndsi >= 0.4 & ndsi < 0.7
ndsi >= 0.7 & ndsi < 0.75
ndsi >= 0.75 & ndsi < 0.8
ndsi >= 0.8 & ndsi < 0.85
ndsi >= 0.85
Radiance (W m−2)
Viewing Zenith Angle
ϕ = 10° − 30° and ϕ = 110° − 130°
Radiance (W m−2)
Viewing Zenith Angle
ϕ = 70° − 90° and ϕ = 90° − 110°
Radiance (W m−2)
Viewing Zenith Angle

Conclusions

- NDSI increases with size of snow particles.
- NDSI increases with snow coverage over land.
- Three different clear-sky snow scene types, permanent snow, fresh snow over land, and sea ice.
- Use NDSI for further separation of fresh snow over land into 2 types, NDSI greater than 0.7 and less than 0.7.
- Possible use of a percentile approach to determine NDSI value because of the dependence of viewing geometry.