Snow BRDF model using non-spherical snow particles and its validation with field measurements

Objective: To improve the GLI cryosphere algorithms such as snow grain size and impurities

BRDF model:

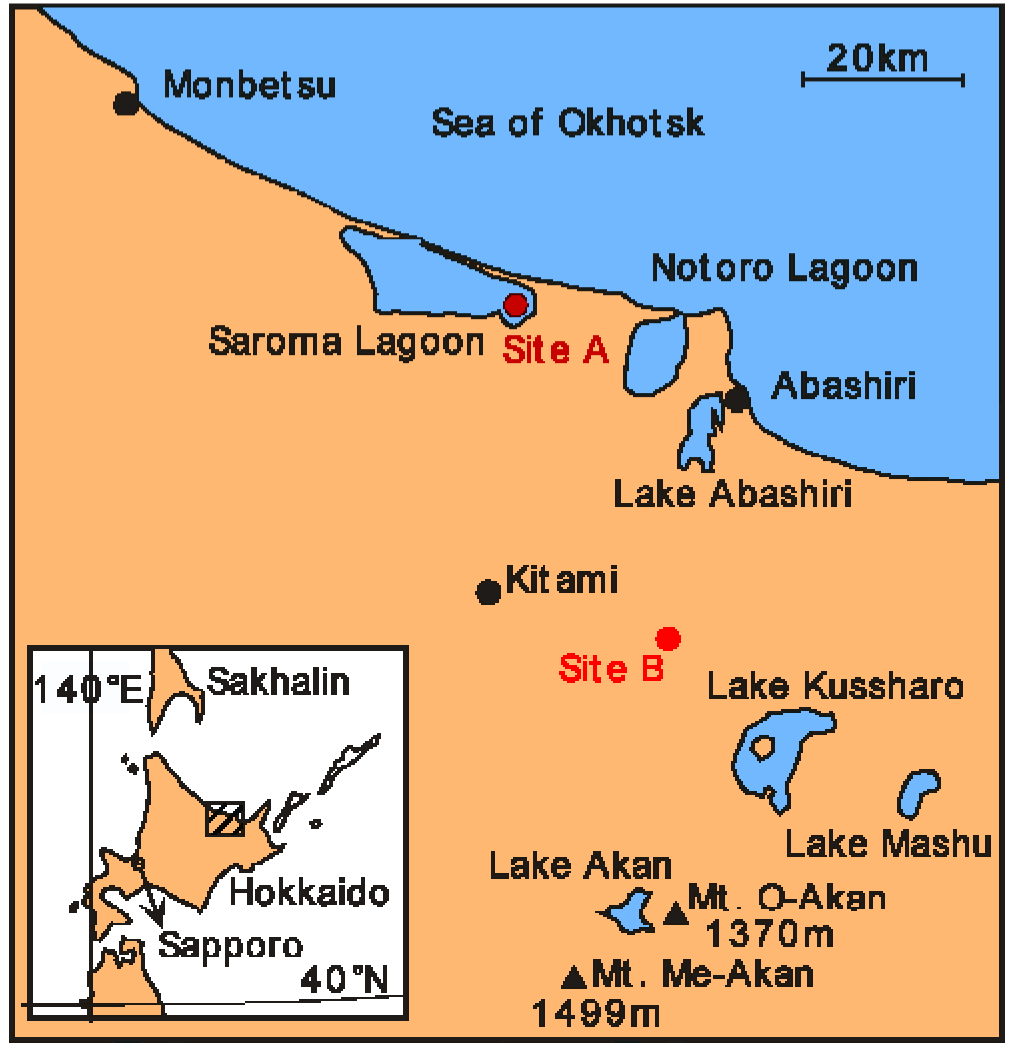
- Ray tracing for single scattering calculation
- Non spherical particles of hexagonal column and ellipsoid
- Doubling and adding method for multiple scattering

Observation:

- February in Eastern Hokkaido
- Snow surface consisted of dendrites crystals
- BRDF observed with FieldSpec FR (ASD Inc., USA)

Field Campaign on February 5-9, 2001 in Hokkaido

- Cold (-10°C) and enough snow (>40cm)
- Homogeneous sea ice (Saroma)
- AMSS (Airborne Multiple Spectral Scanner)
- FieldSpec FR (λ = 0.35-2.5 μm, BRDF, albedo)
- FTIR (λ = 2-14 μm, emissivity)
- Snow pit work (grain size and impurities)



Solar spectral region

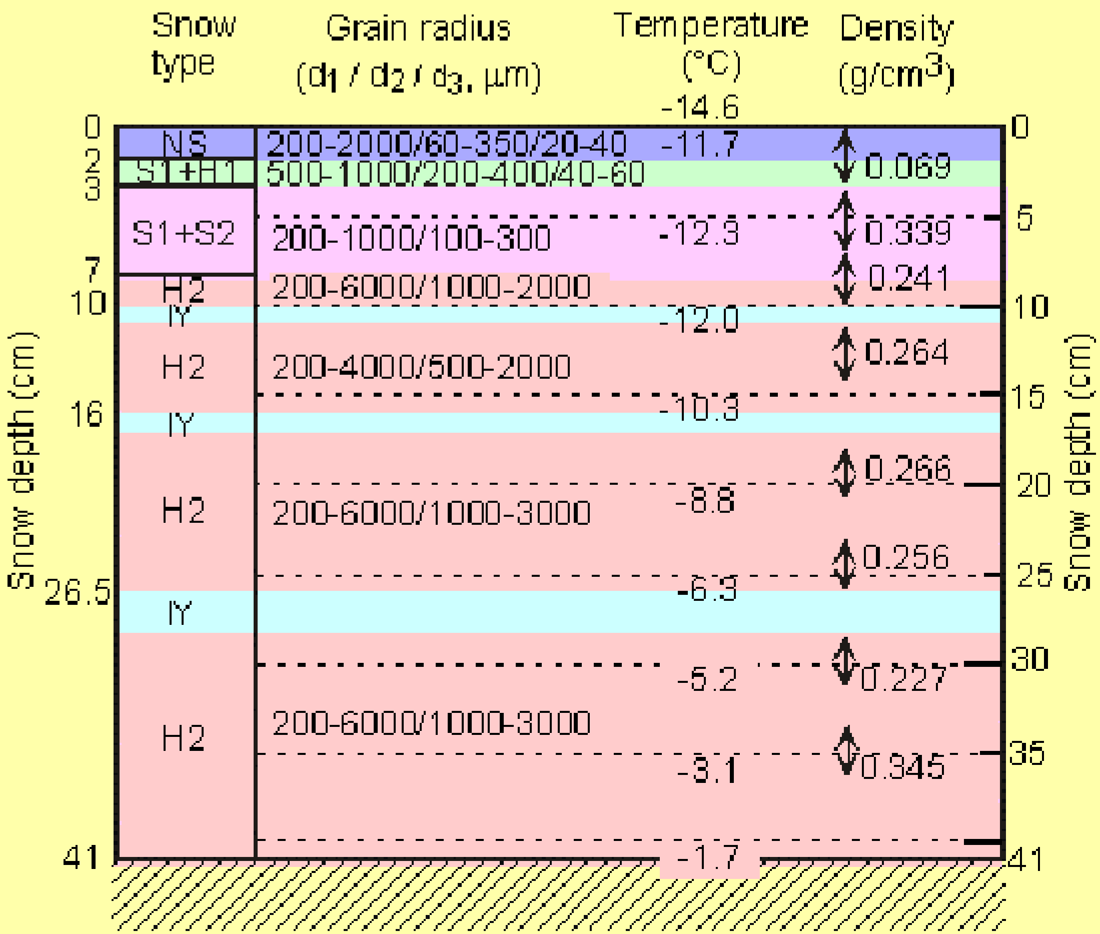
FieldSpec FR

- Spectral BRDF and albedo
- λ = 0.35-2.5 μm
- $\Delta\lambda$ = 10 nm

Snow pit work

- Snow grain size
- Impurities, etc

Snow pit work result

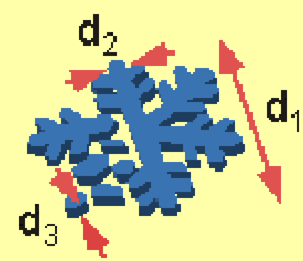


February 9, 2001 / Site B
Observed at 09:00 - 10:30 LT
New snowfall: Feb. 8 = 2 cm

Snow types:

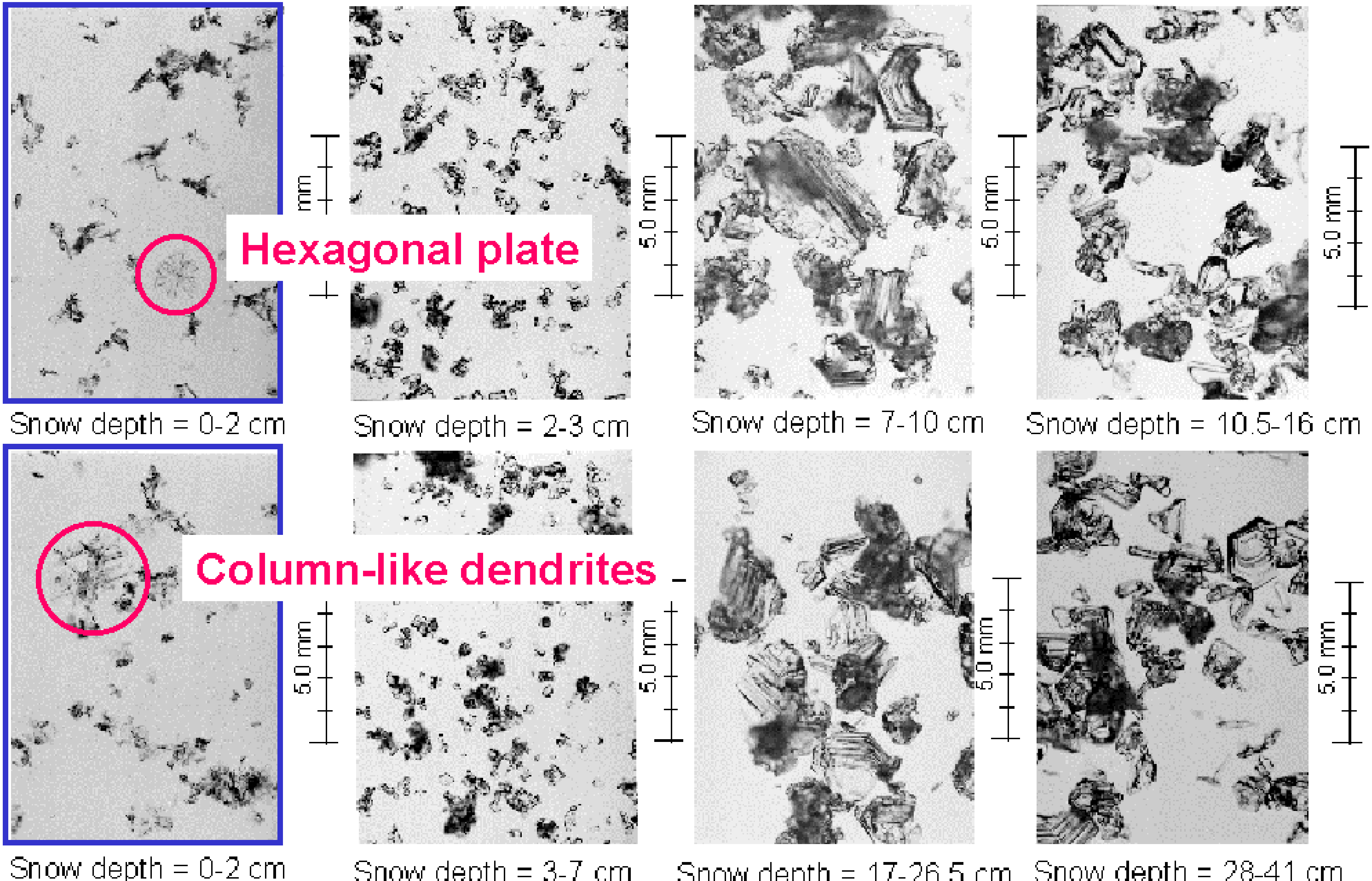
NS: New snow
S1: Fine-grained old snow
H1: Faceted crystals
H2: Depth hoar
IL: Ice layer

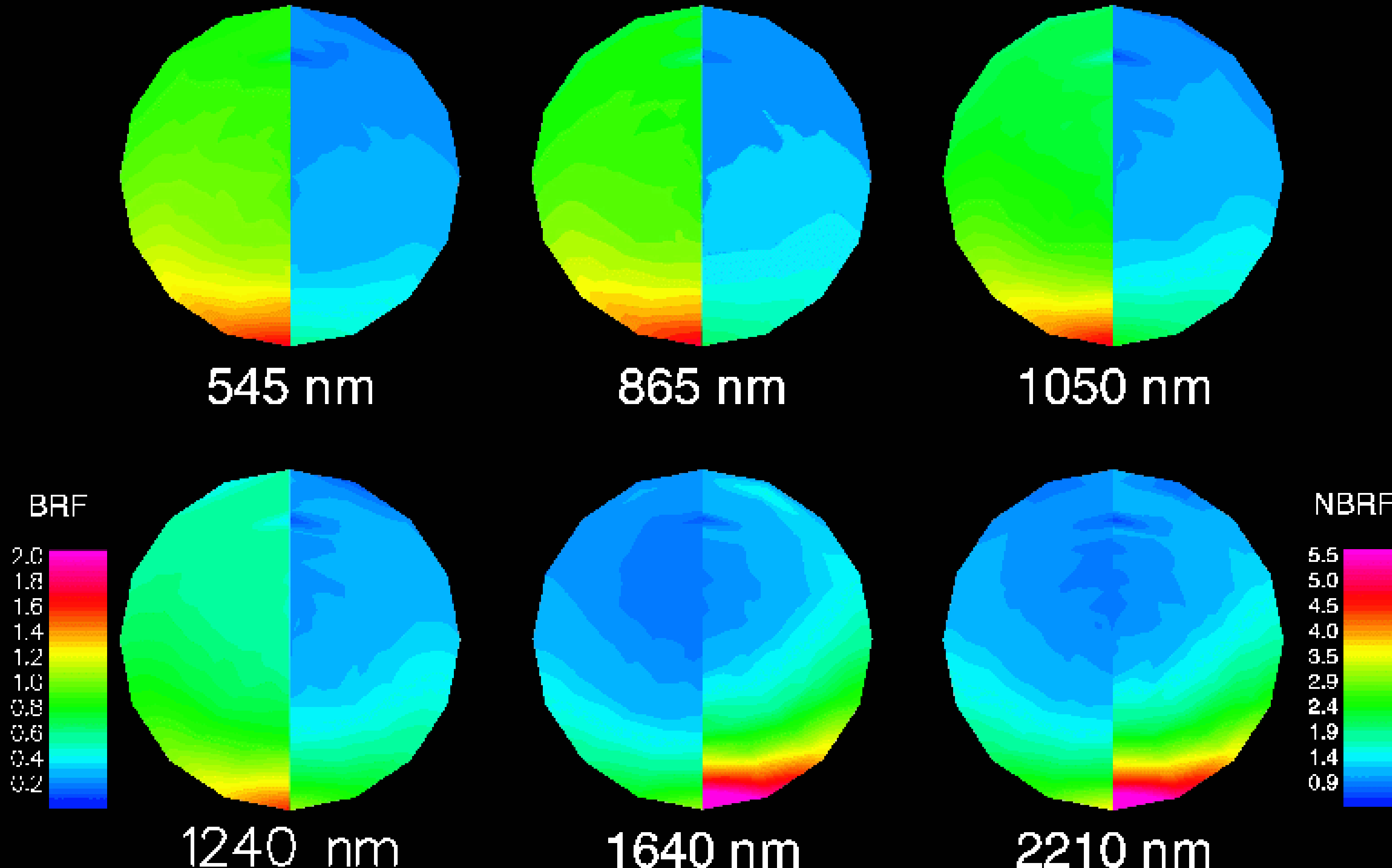
Snow grain size



Crystal full size = 200-2000 μm, Branch width = 60-350 μm,
Crystal thickness = 20-40 μm for dendrites at snow surface

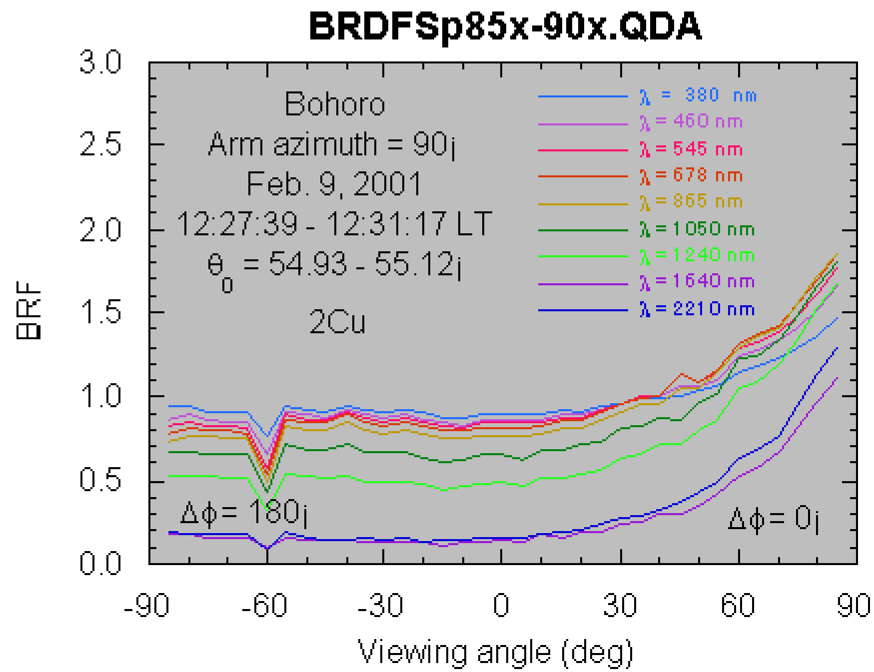
Micrographs of snow crystals taken on February 9, 2001 at site B

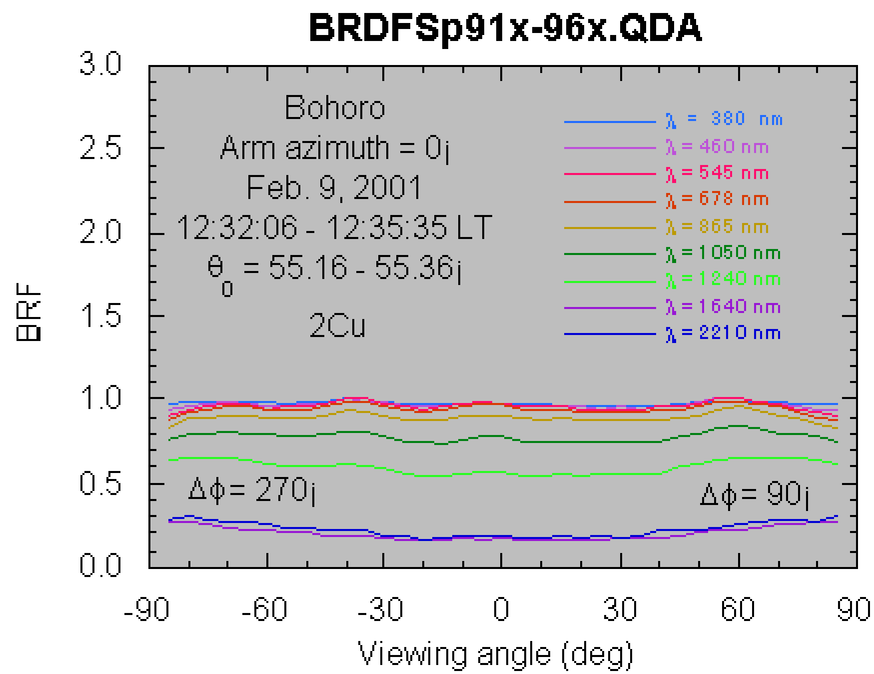



545 nm
865 nm
1050 nm
BRF
2.0
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
1240 nm
1640 nm
2210 nm
NBRF
5.5
5.0
4.5
4.0
3.5
2.9
2.4
1.9
1.4
0.9

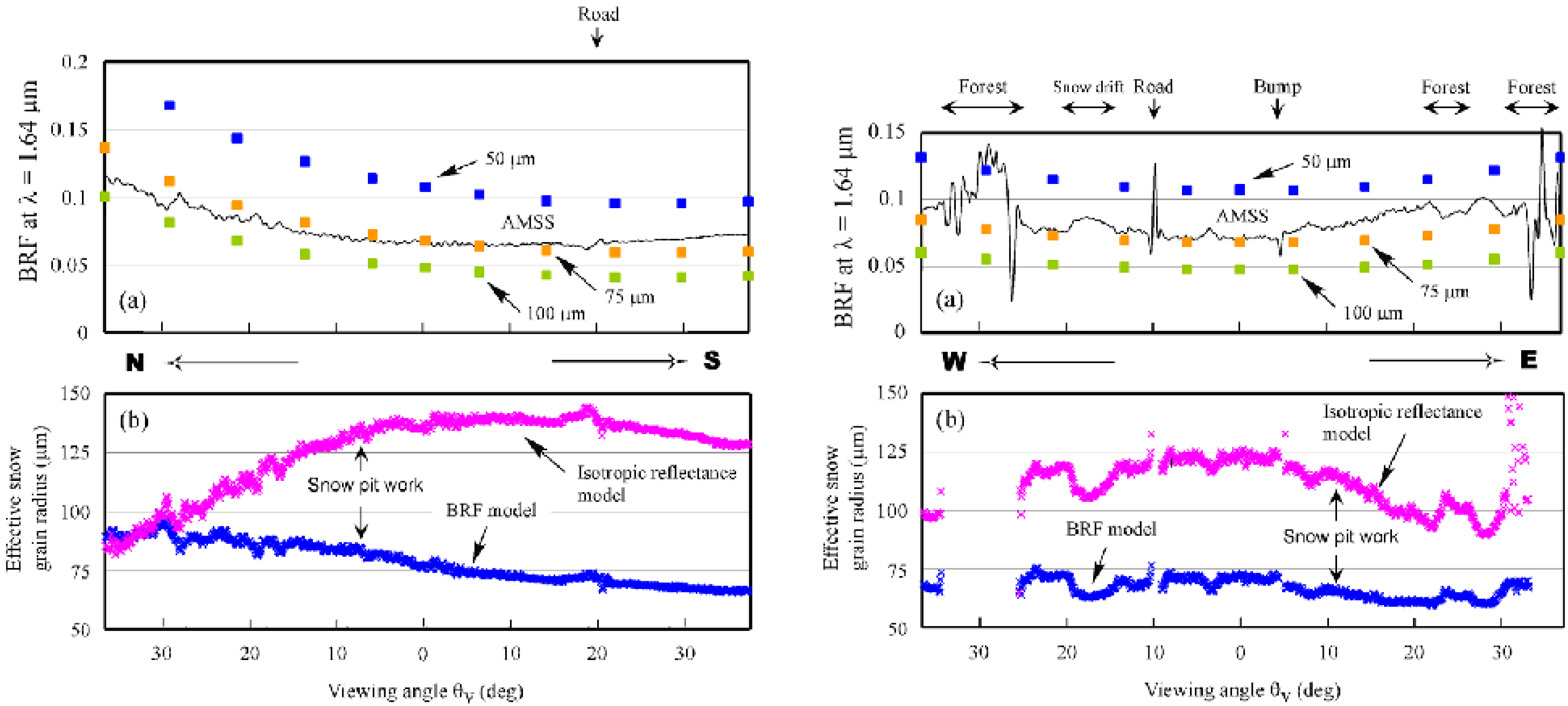
Measured BRDFs along azimuth = 0-180° and 90-180°

- Anisotropic reflection properties at near infrared wavelengths
- Flat pattern in backscattering region at any wavelength
- Increasing tendency in side scattering region at near infrared wavelengths



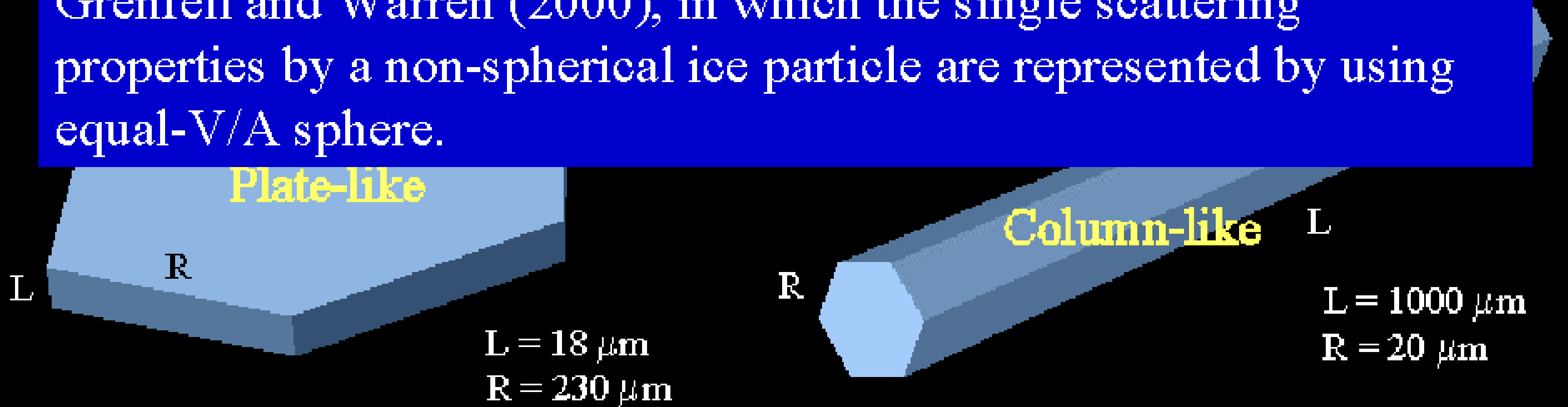


Snow BRDF model, observed reflectance and retrieved results of snow parameters

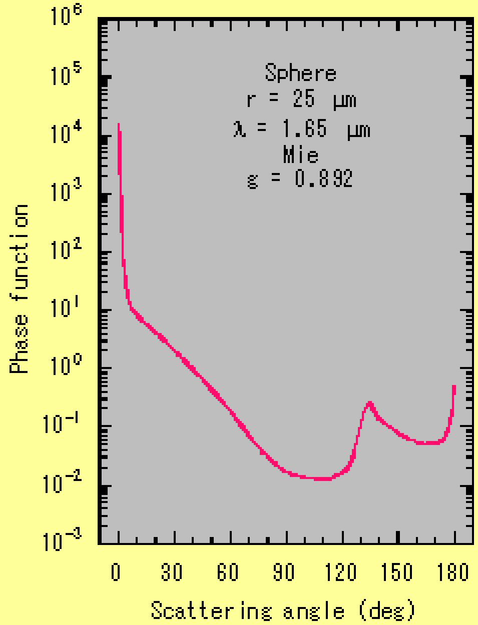


Ray tracing and Mie theory

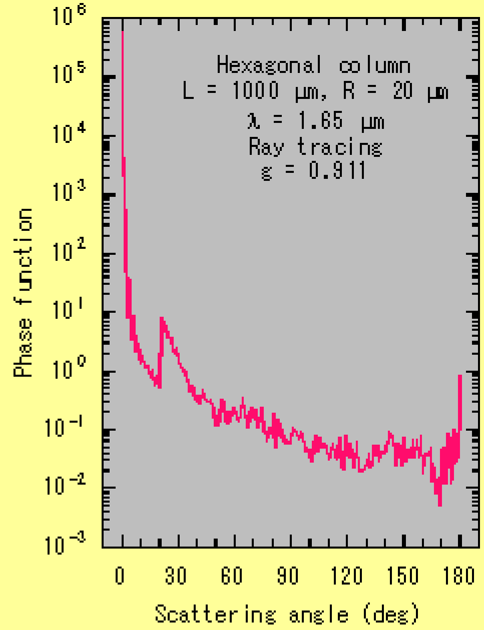
1. Radius of sphere is determined from the spectral albedo fitting between calculation and measurement.
2. Sizes of non-spherical ice particles are assumed by the study of Grenfell and Warren (2000), in which the single scattering properties by a non-spherical ice particle are represented by using equal-V/A sphere.



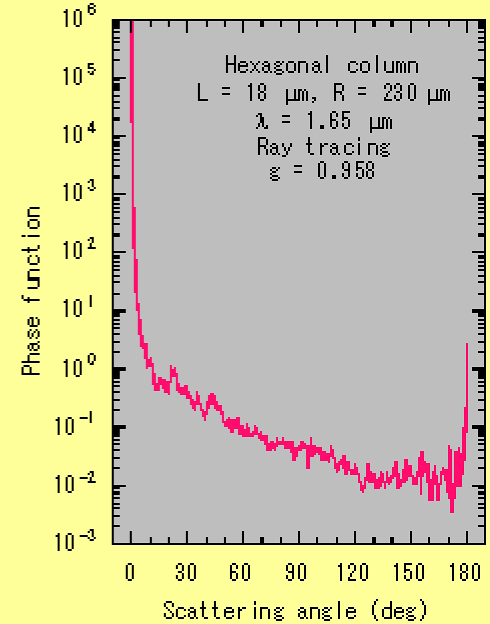
Sphere



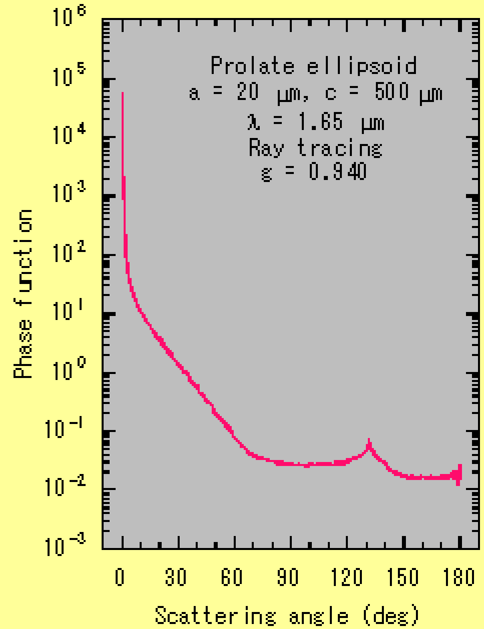
Hexagonal column



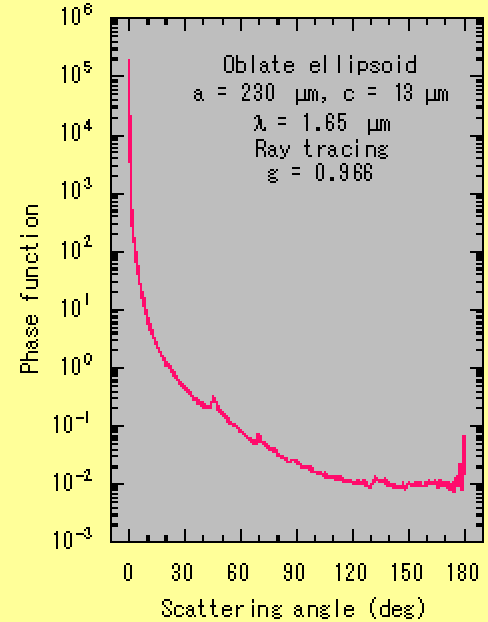
Hexagonal plate



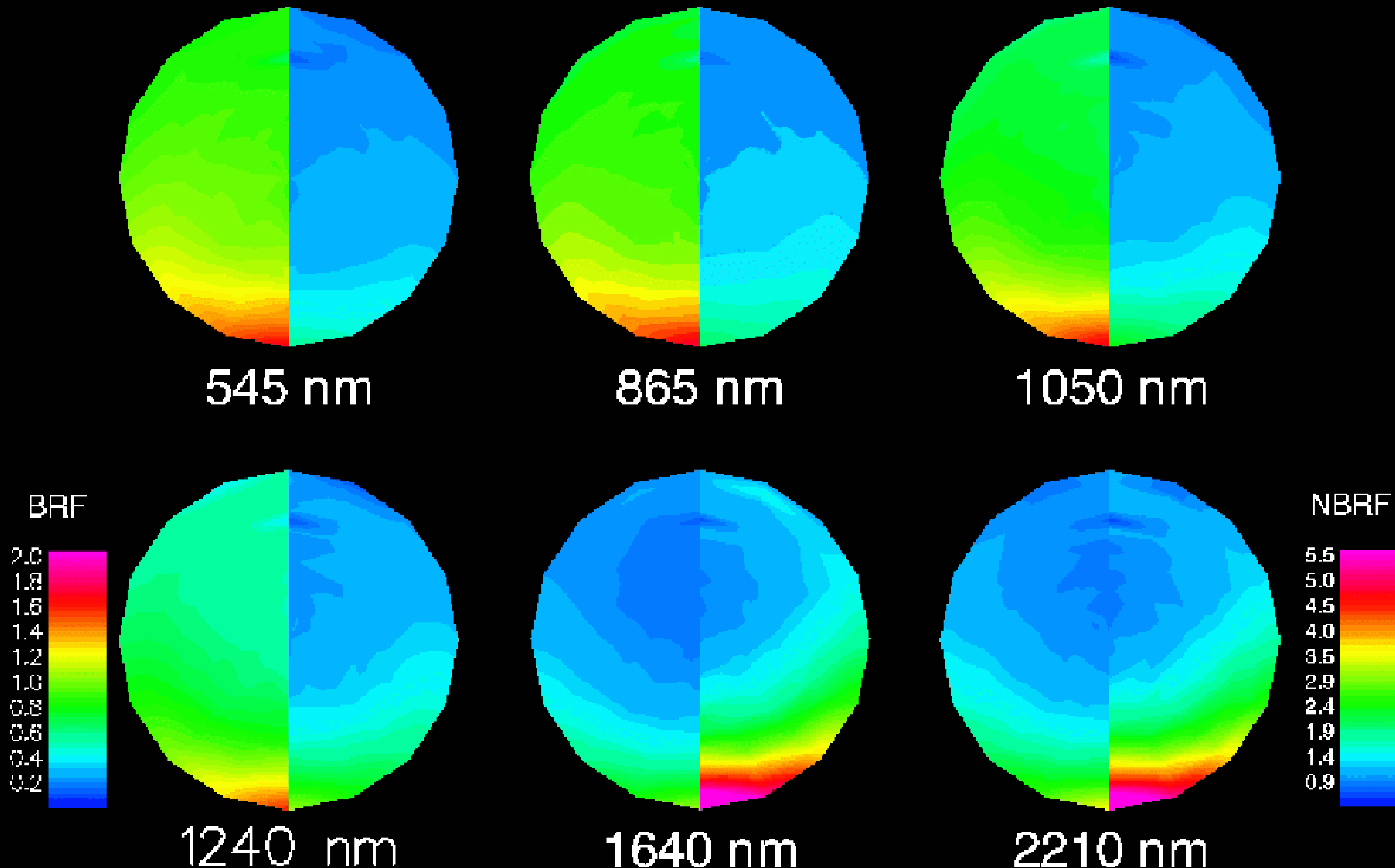
The asymmetry factors of prolate and column-like crystals are smaller than oblate and plate-like crystals. The reason of smaller asymmetry factor of sphere is due to the smaller size compared with the other crystals.



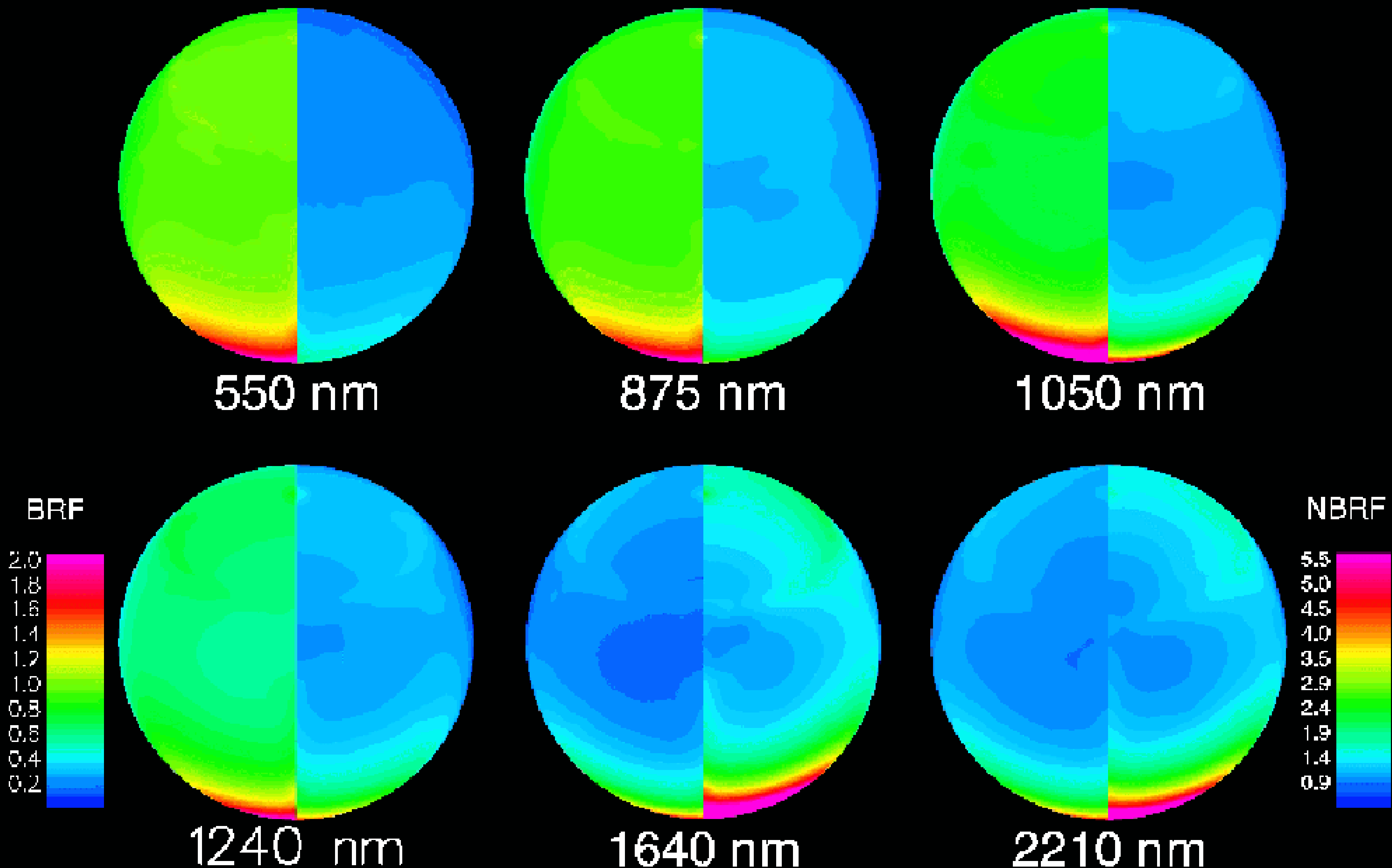
Prolate



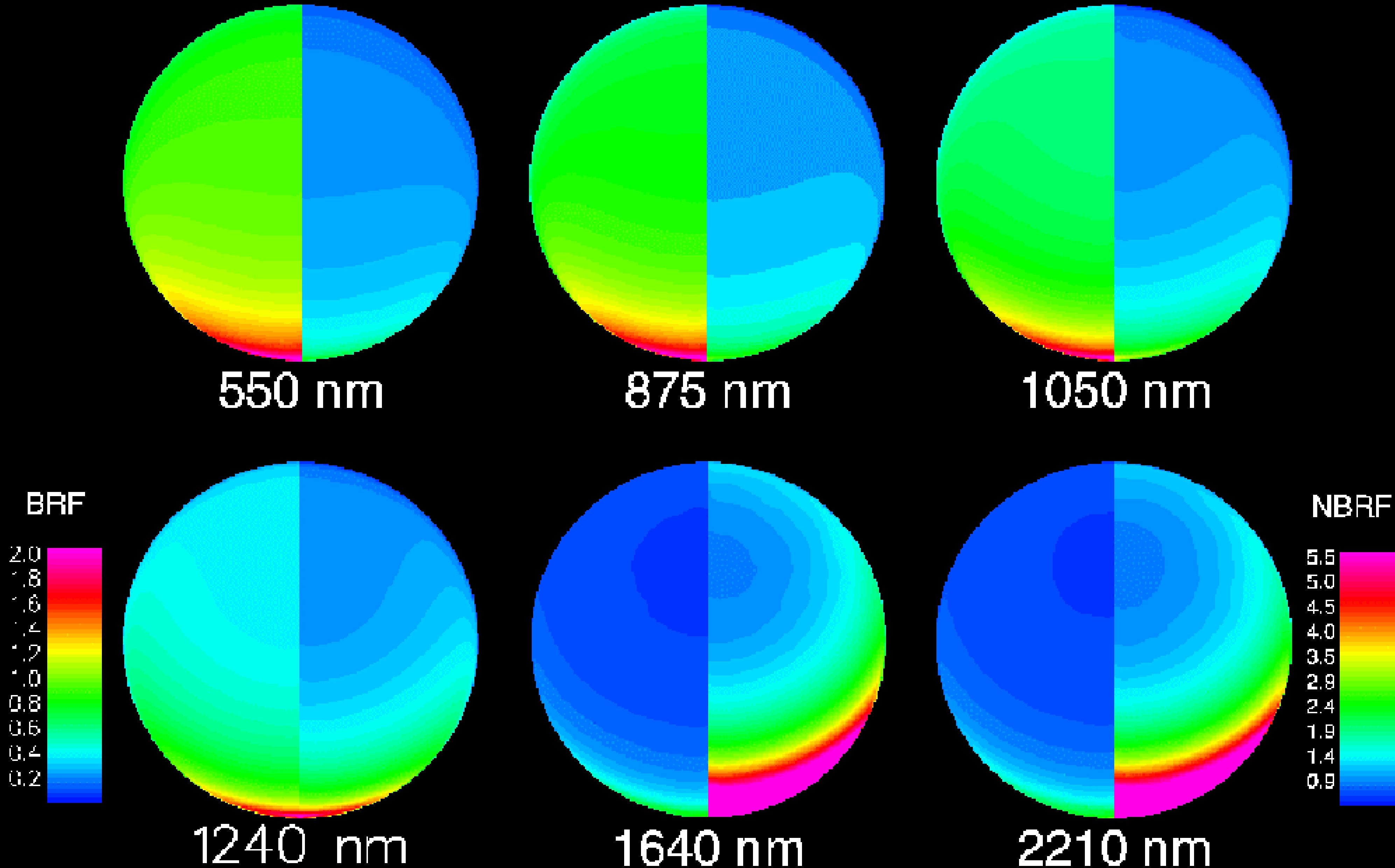
Oblate



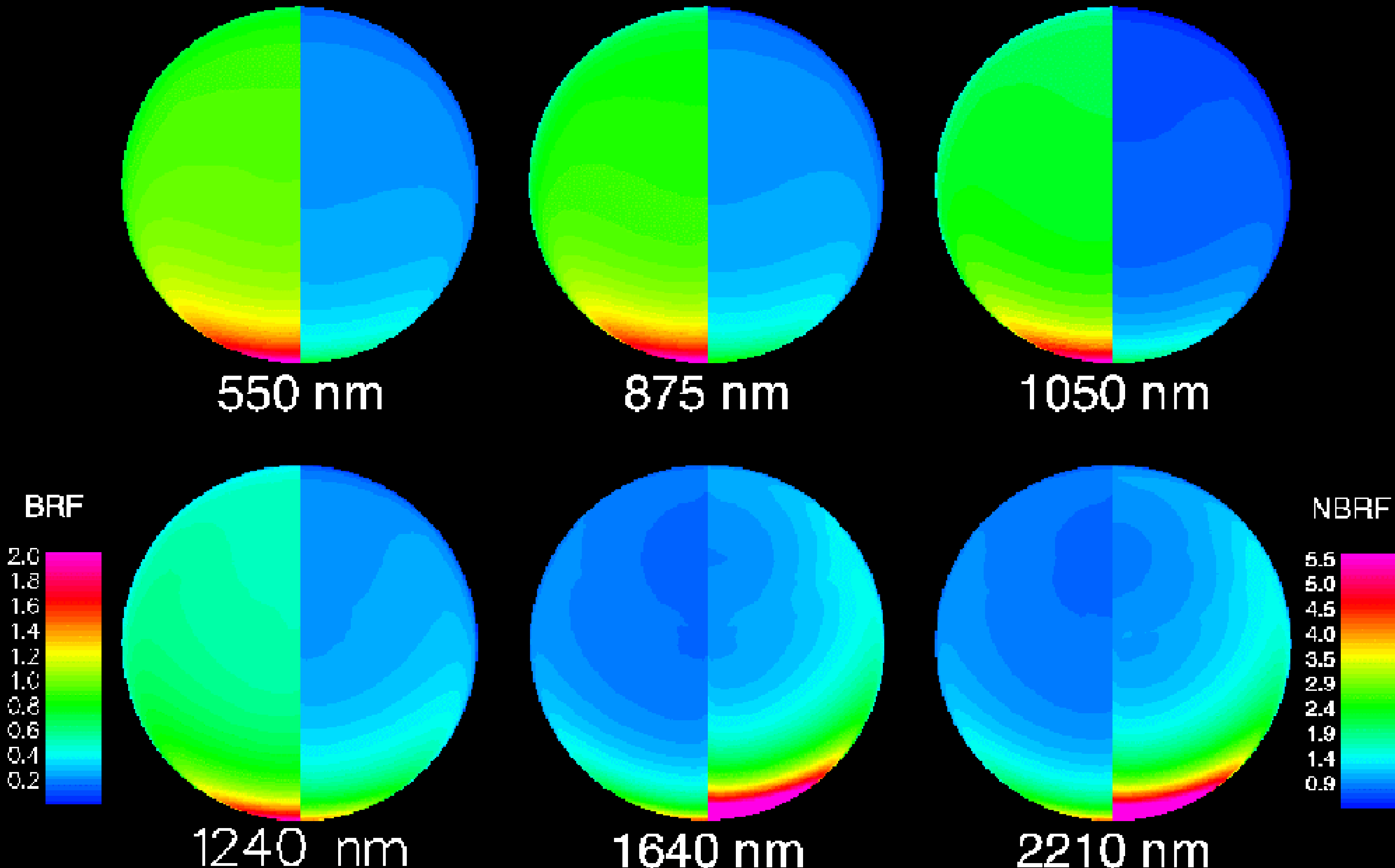
Observation (February 9, 2001, Surface = dendrites)



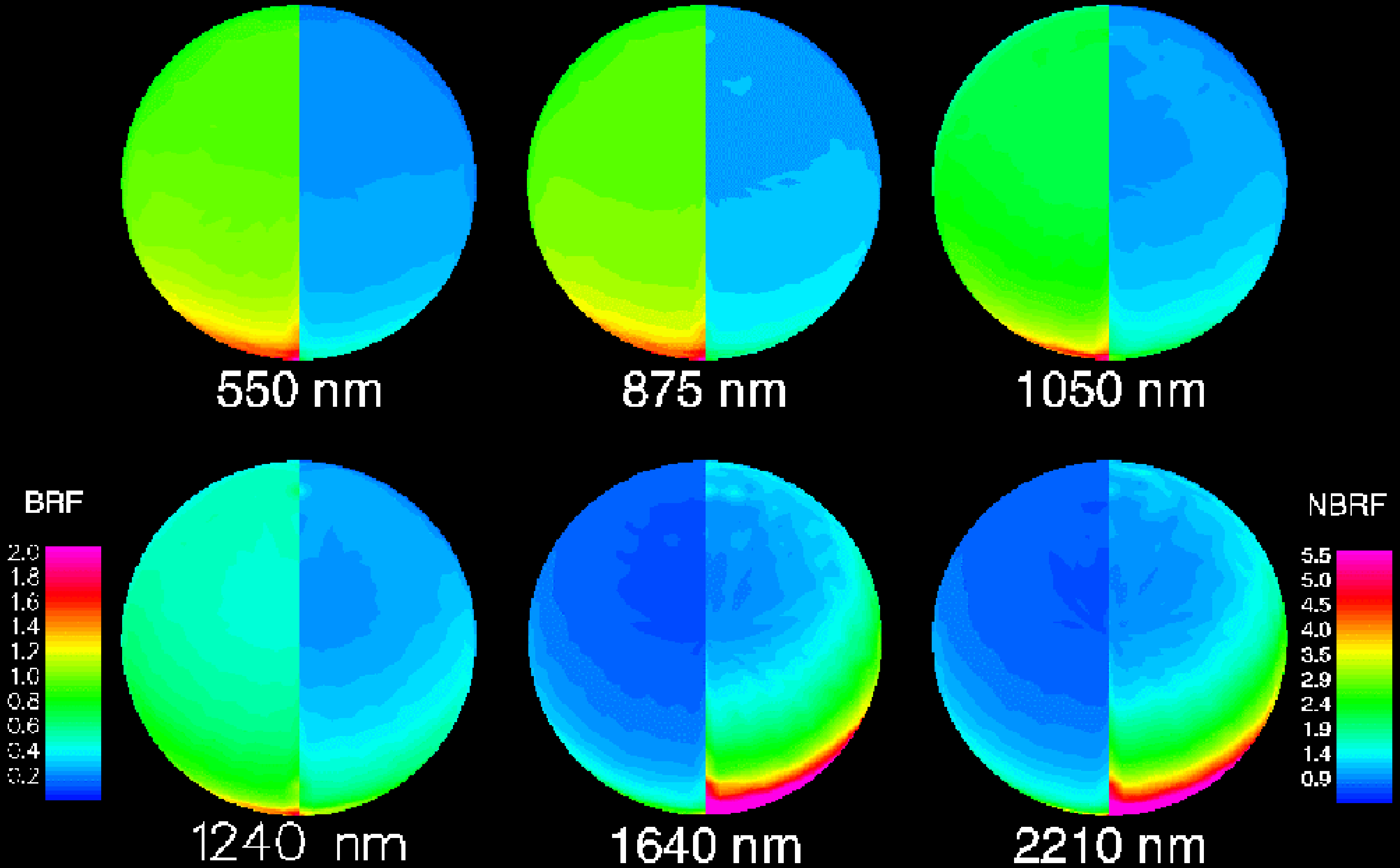
Sphere (r=25 μm)



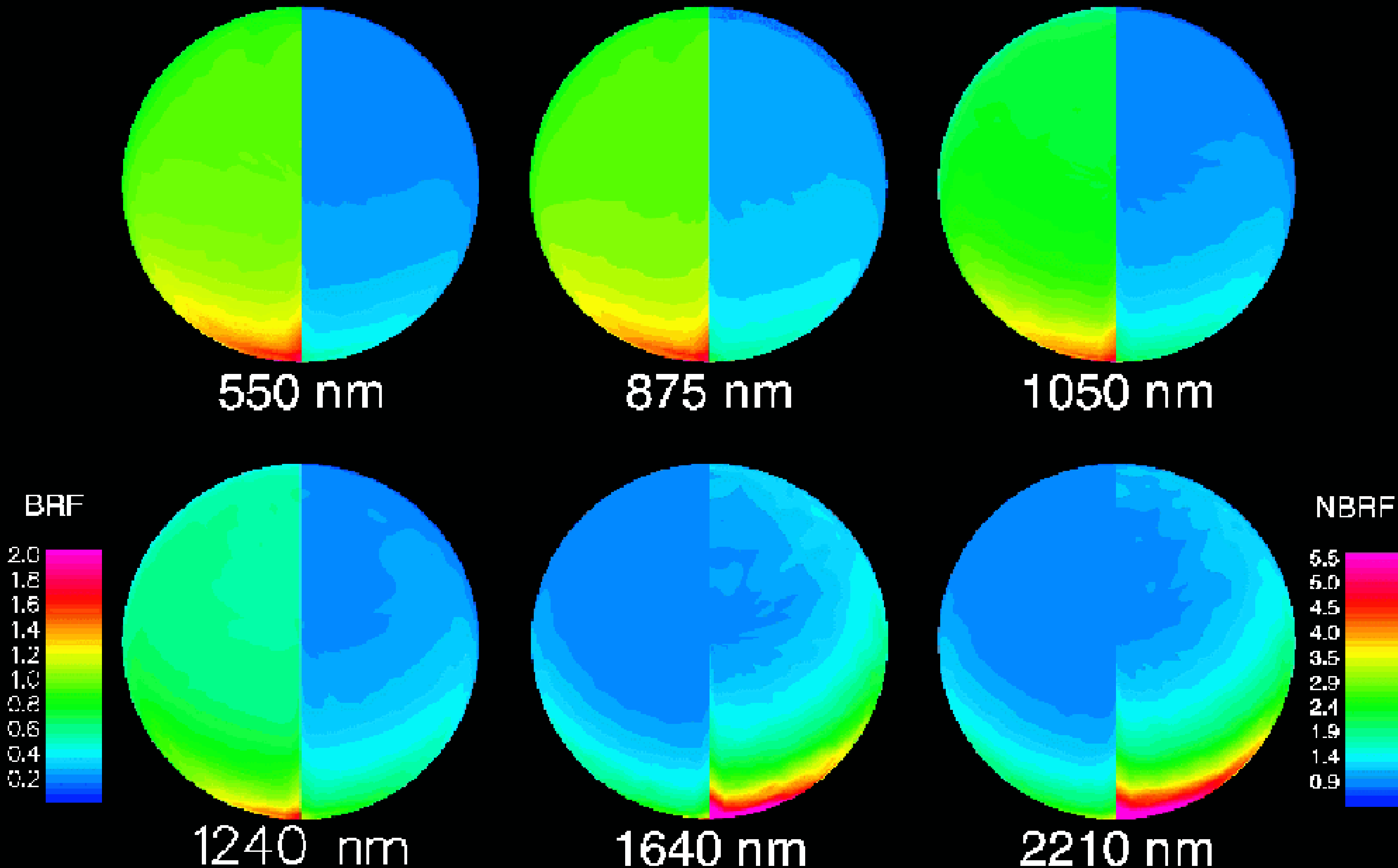
Oblate (a=230 μm, c=13 μm)



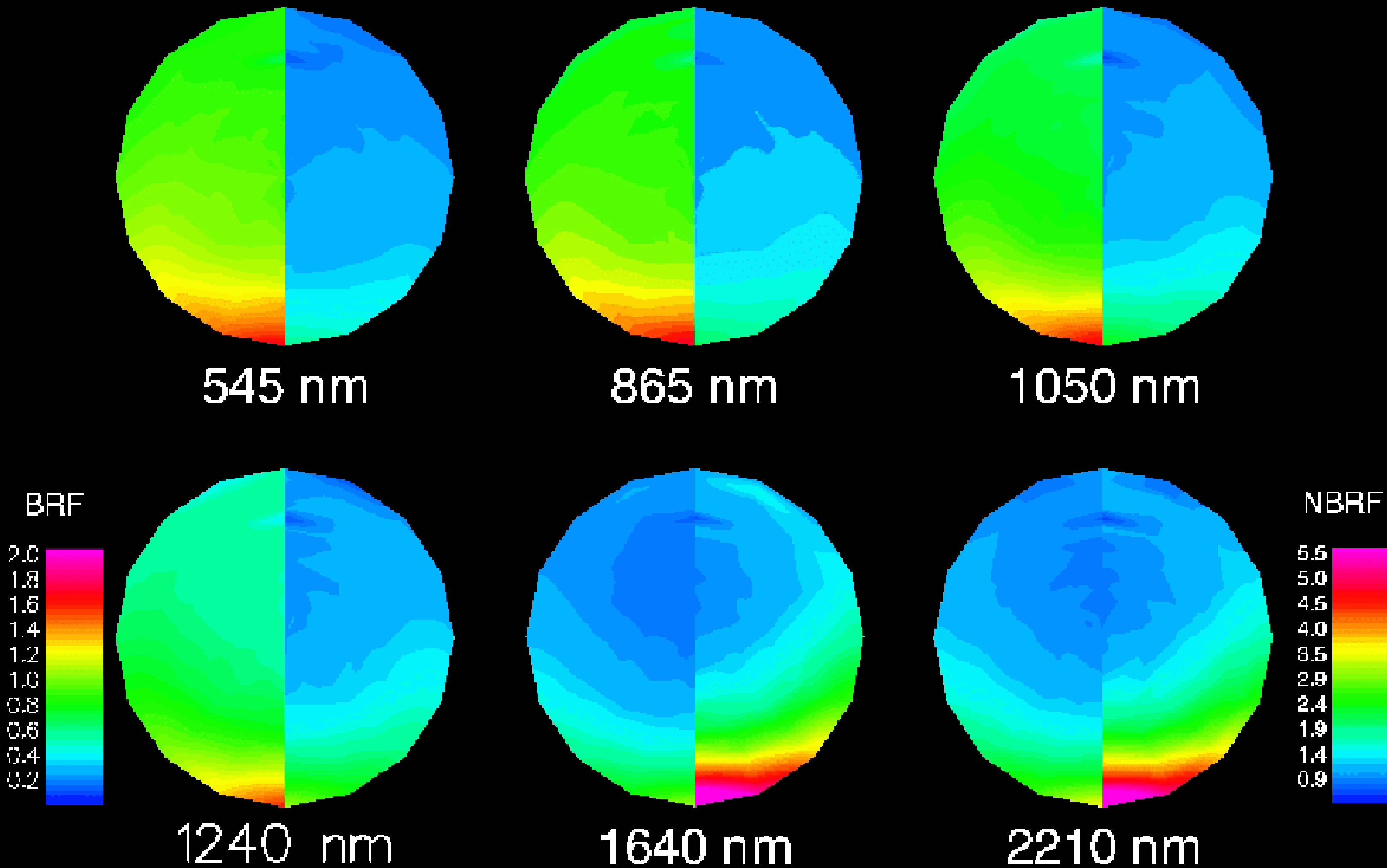
Prolate ($a=20\ \mu m$, $c=500\ \mu m$)



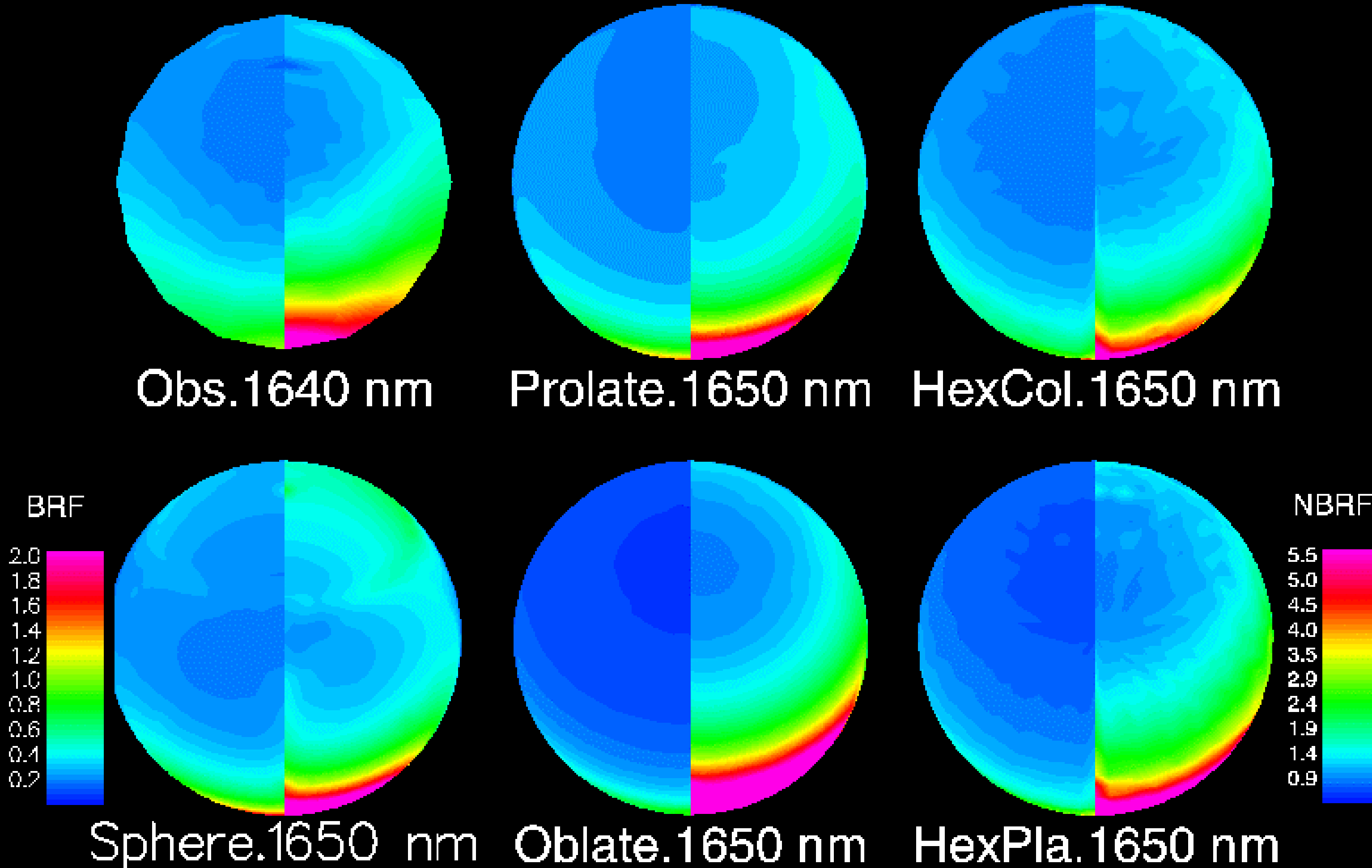
Hexagonal plate (L=18μm, R=230 μm)



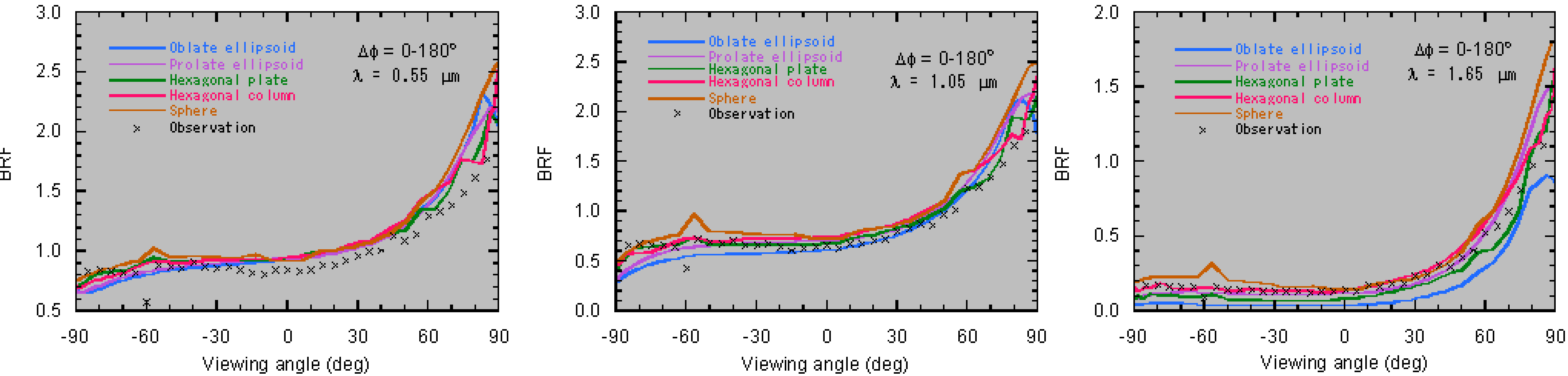
Hexagonal column (L=1000 μm, R=20 μm)



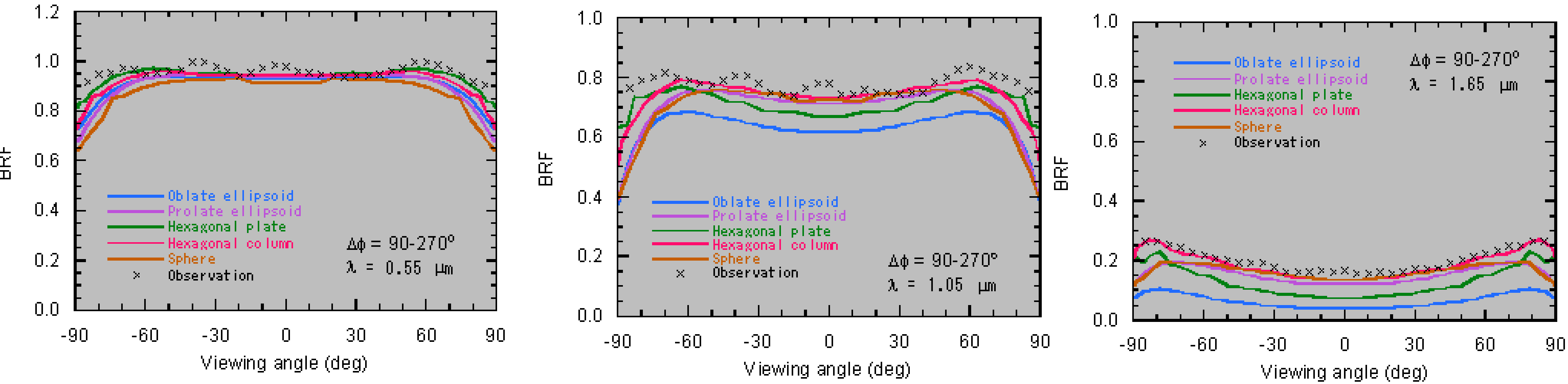
Observation (February 9, 2001, Surface = dendrites)


Obs.1640 nm
Prolate.1650 nm
HexCol.1650 nm
BRF
2.0
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
Sphere.1650 nm
Oblate.1650 nm
HexPla.1650 nm
NBRF
5.5
5.0
4.5
4.0
3.5
2.9
2.4
1.9
1.4
0.9

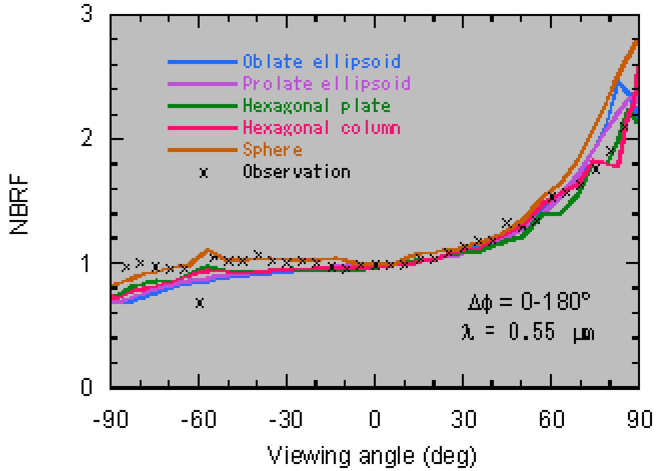
Snow BRF along azimuth = 0-180° and 90-180°

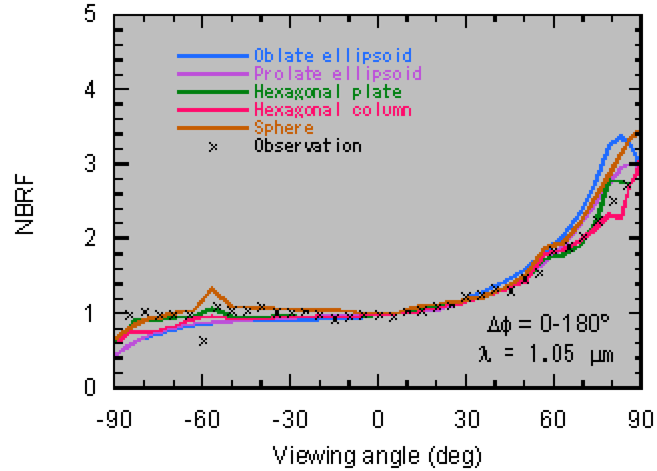


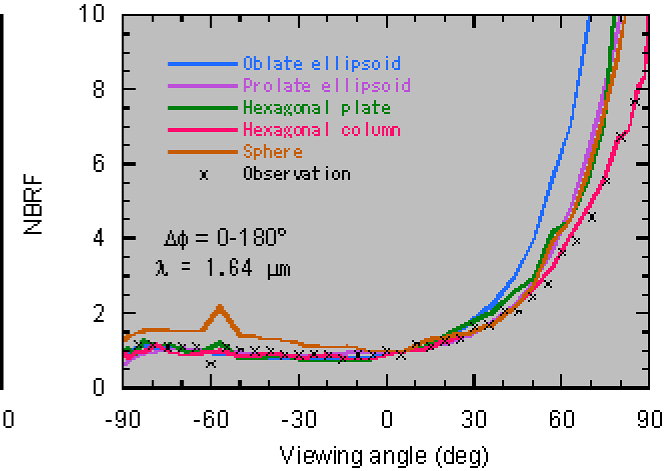
Oblate and hexagonal plate are too low at NIR



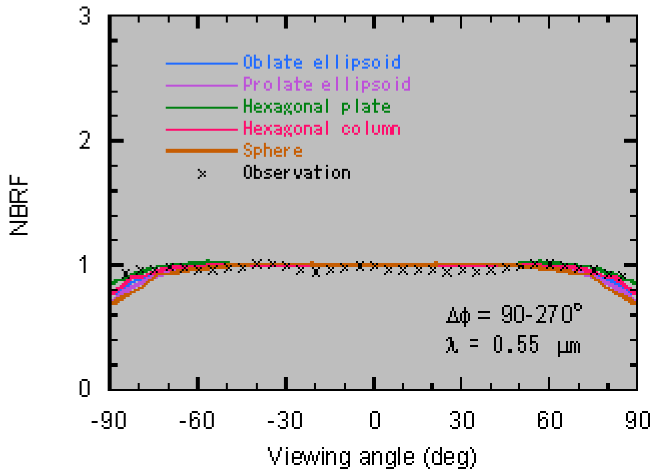
Snow NBRF along azimuth = 0-180° and 90-180°

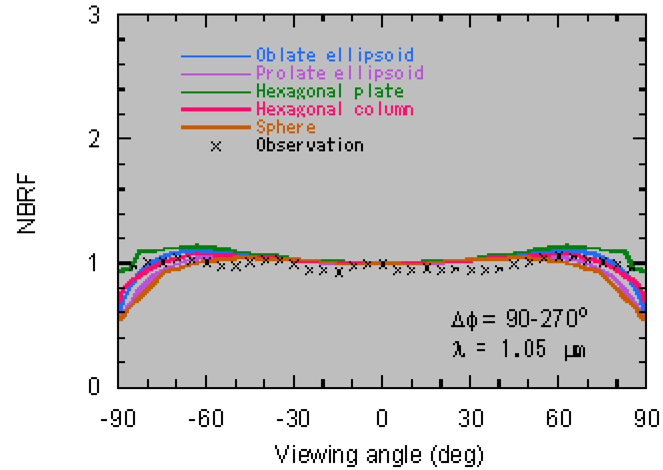


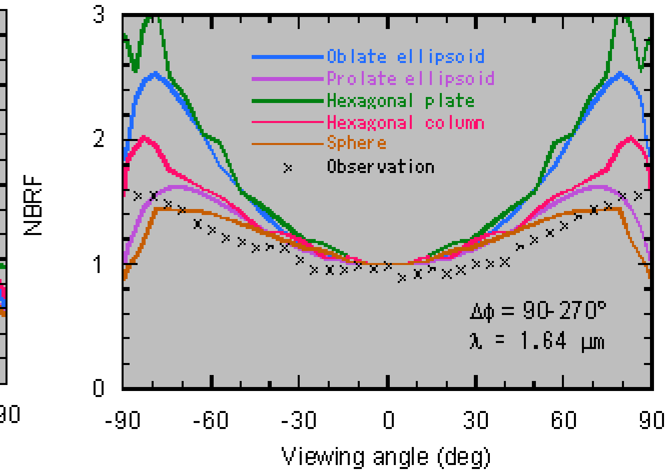


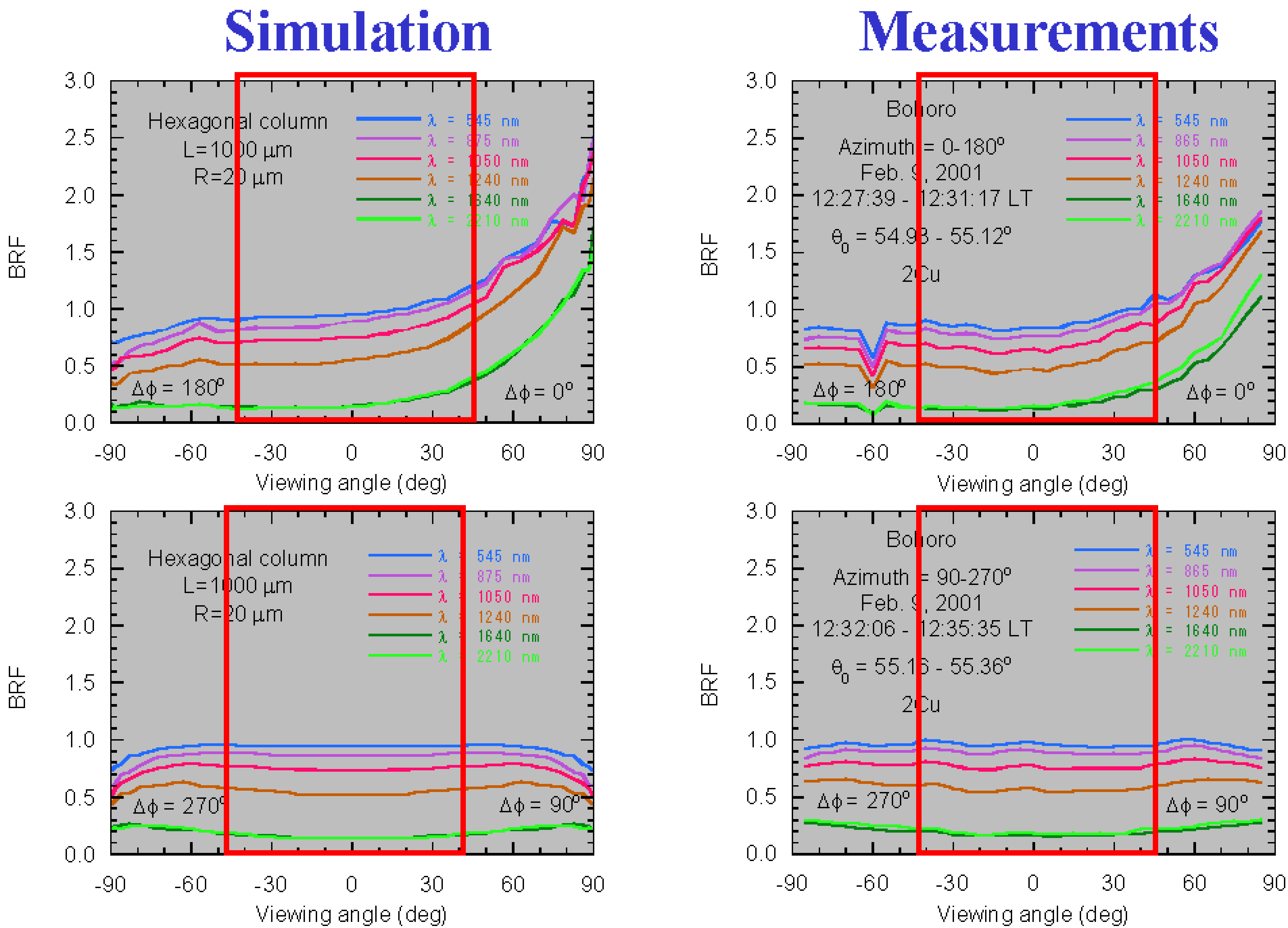


Hexagonal column gives the best fit for the measurements









Simulation
Measurements
Hexagonal column
L=1000 µm
R=20 µm
λ = 545 nm
λ = 875 nm
λ = 1050 nm
λ = 1240 nm
λ = 1640 nm
λ = 2210 nm
Δφ = 180°
Δφ = 0°
BRF
Viewing angle (deg)
Bohoro
Azimuth = 0-180°
Feb. 9, 2001
12:27:39 - 12:31:17 LT
θ0 = 54.98 - 55.12°
2Cu
λ = 865 nm
Δφ = 270°
Δφ = 90°
Azimuth = 90-270°
12:32:06 - 12:35:35 LT
θ0 = 55.16 - 55.36°

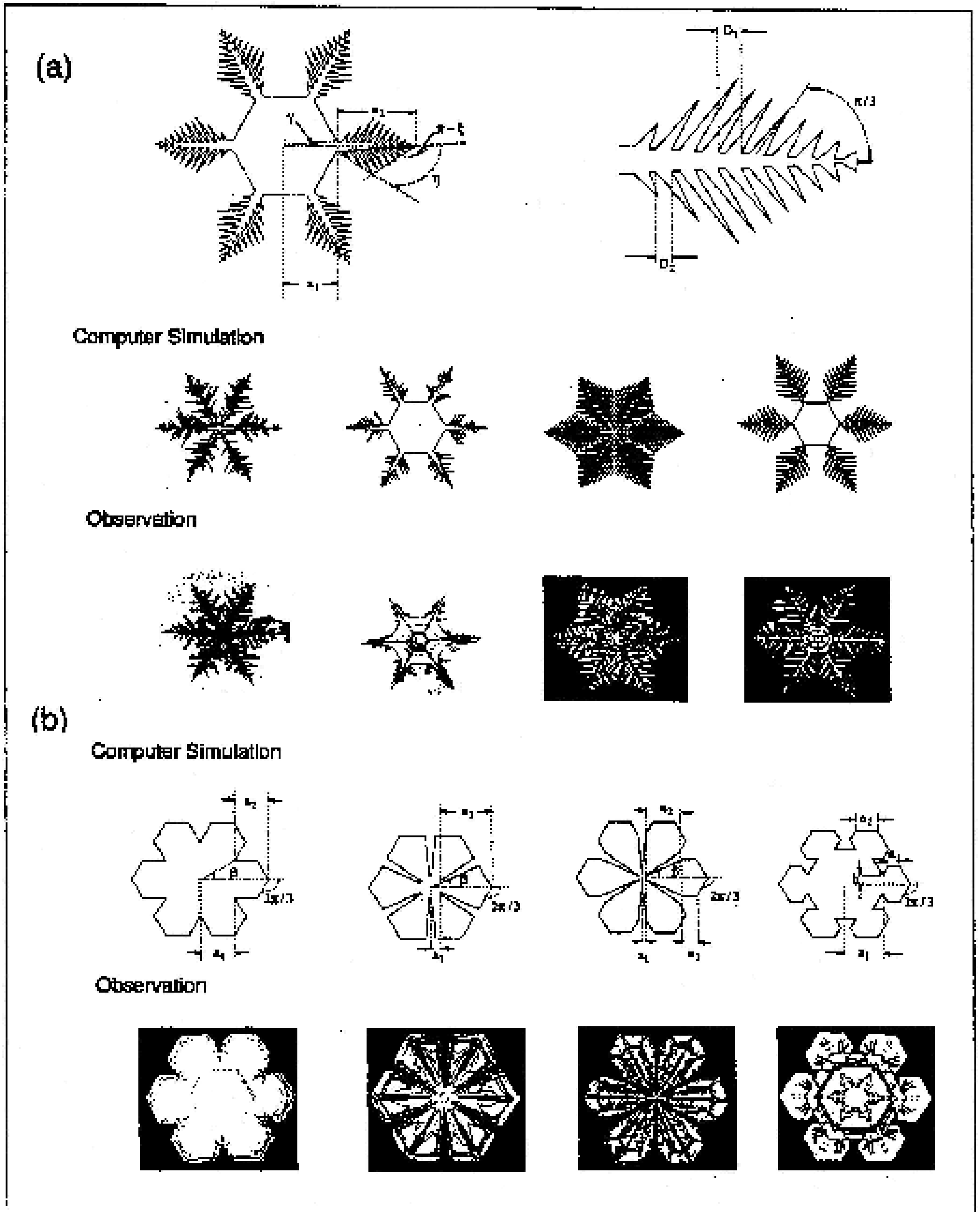


Figure 1: (a) Geometries for fernlike and dendritic ice crystals. (b) Geometries for ice crystals with broad and sectorlike branches.

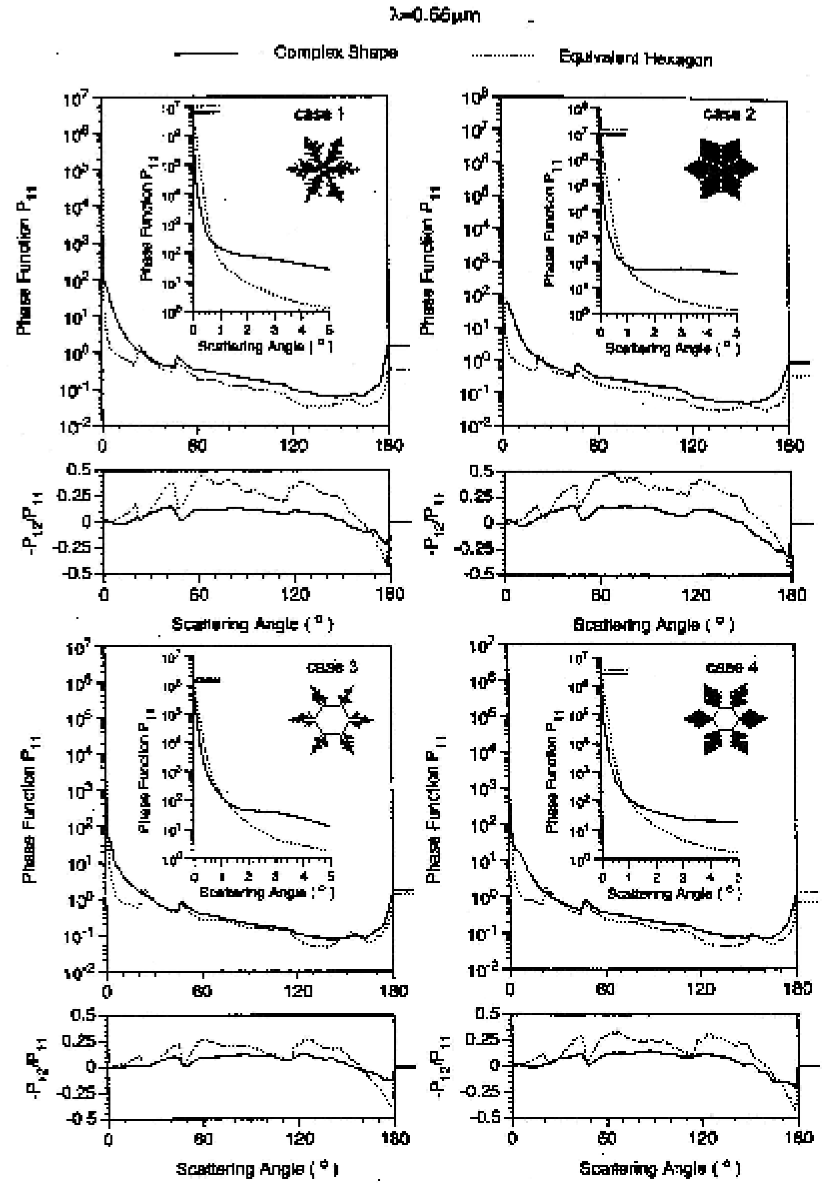


Figure 4: Phase function and the degree of linear polarization for the fernlike and dendritic crystals at 0.55 μm. The parameters defined in Figure 1a for determining the ice crystal dimensions, (γ, η, ξ, N, ρ, a_1, a_2, L), are (30°, 30°, 35°, 20, 0.5, 20 μm, 600 μm, 50 μm), (30°, 30°, 35°, 10, 0.556, 20 μm, 600 μm, 50 μm), (5°, 30°, 35°, 10, 0.5, 100 μm, 150 μm, 50 μm), and (3°, 40°, 30°, 10, 0.5, 100 μm, 240 μm, 50 μm) for cases 1–4, respectively. L denotes ice crystal thickness. Also shown are the results for the equivalent hexagonal plates.

Yang and Liou (1998): *Contr. Atmos. Phys.*, **71**, 223-248.

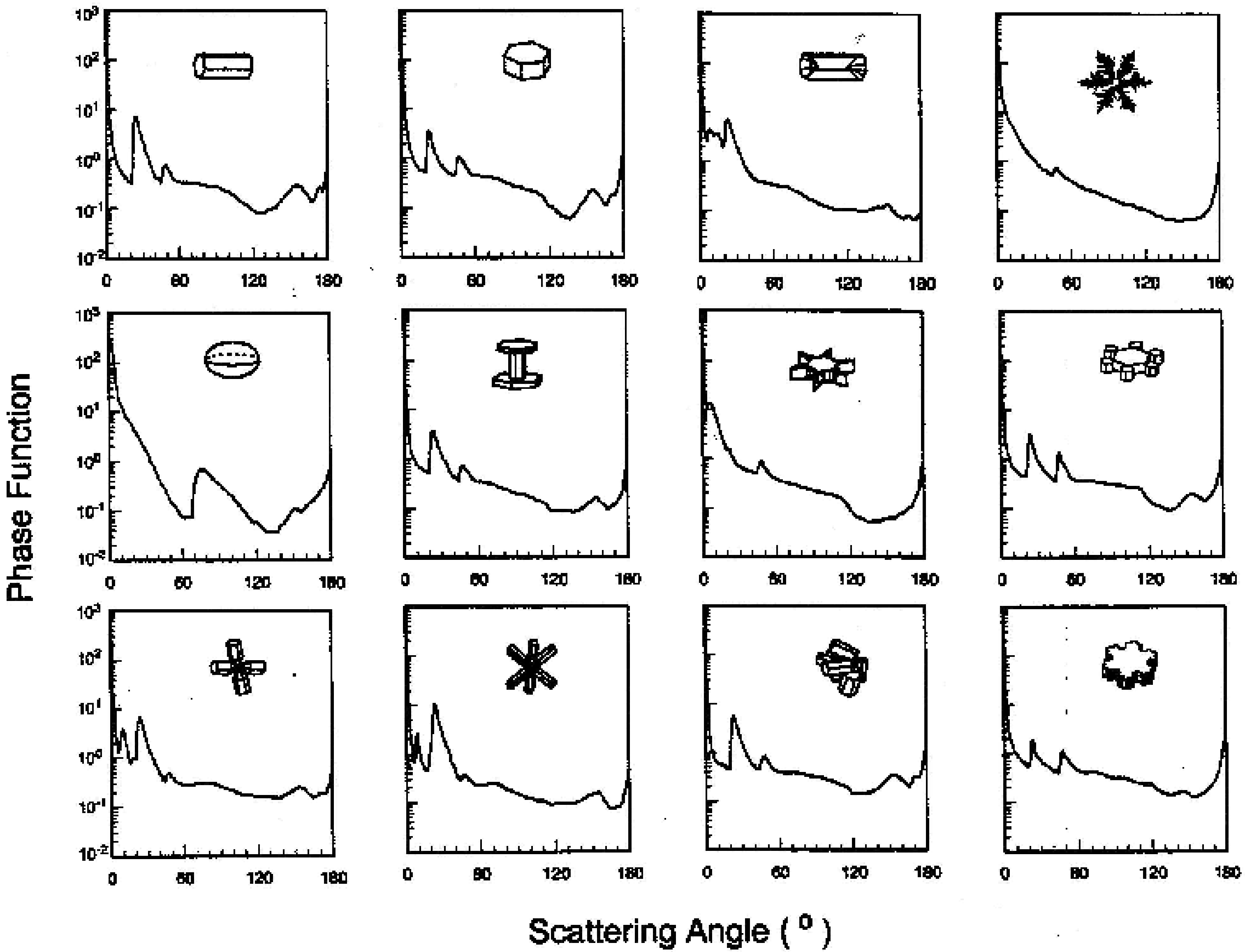


Figure 11: Comparison of phase function for various ice crystal shapes at 0.63 μm wavelength.

Yang and Liou (1998): *Contr. Atmos. Phys.*, **71**, 223-248.

Effect of crystal surface roughness on phase function

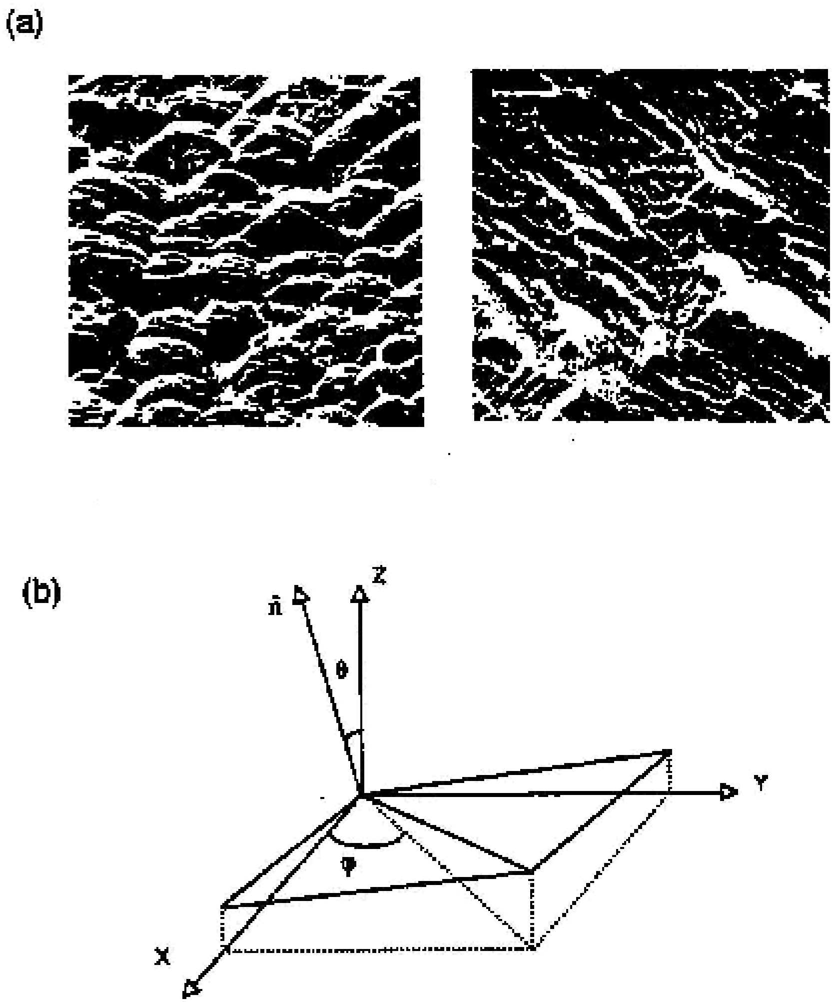


Figure 3: (a) Surface roughness of ice crystals observed by using a scanning electron microscope (after Cross, 1968). (b) The geometry for the tilt of a small facet on rough surface.

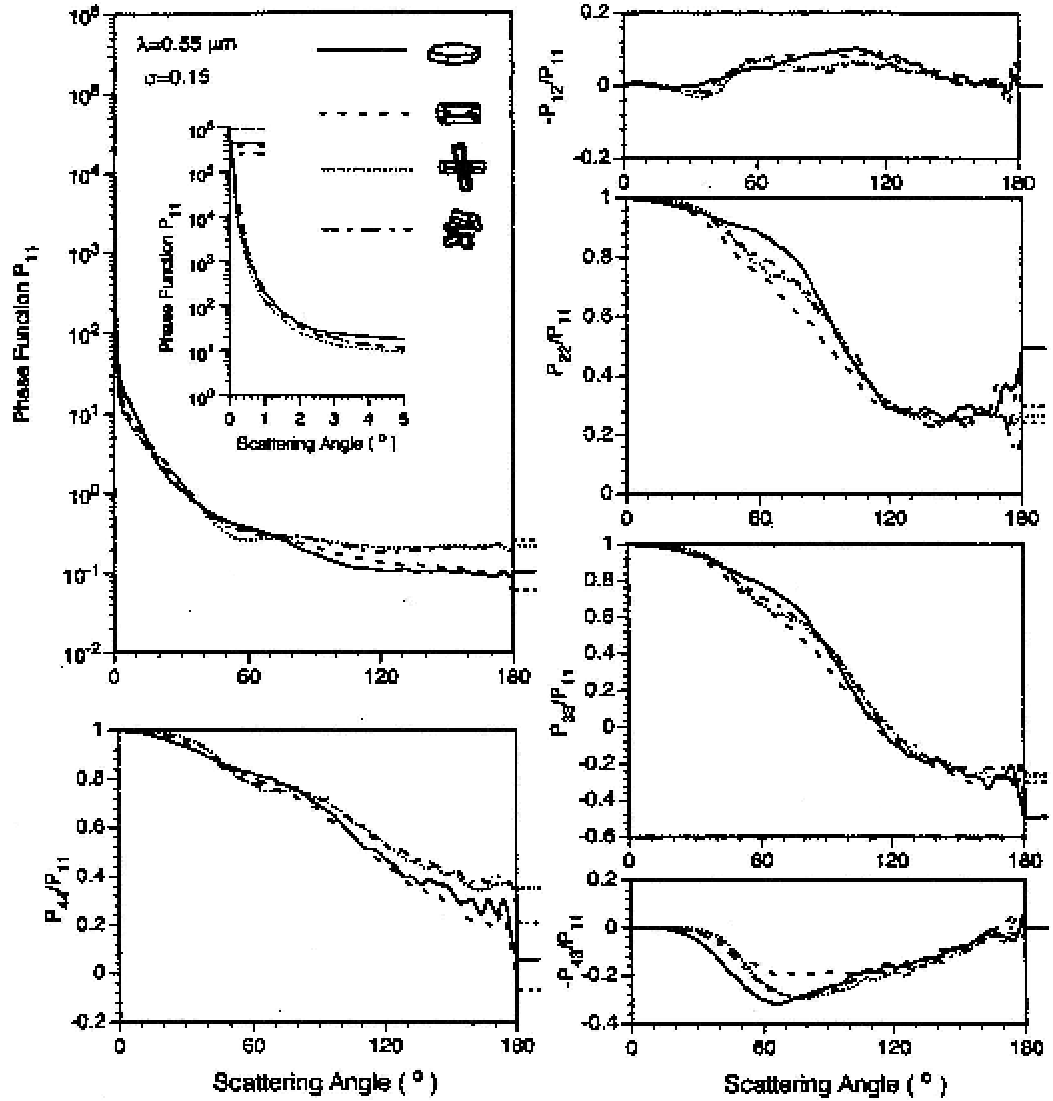


Figure 10: Comparison of phase matrix for plates, hollow columns, bullet rosettes, and aggregates for a substantial roughness condition.

Yang and Liou (1998): *Contr. Atmos. Phys.*, **71**, 223-248.

Conclusion

- Hexagonal column is the best model for dendrites snow BRDF in the models of oblate, prolate, HC, HP and sphere.
- Smallest dimension (2R) of hexagonal column corresponded to measured branch width (d2) or thickness (d3) of snow crystal .

Future works

- Investigation of non-spherical particles for different types of snow crystals
- Validation of BRDF model for the crystal having rough surface with the field data (BRDF and micrograph of crystal surface)