

# Multiangle Observations of Directional Reflectances of Snow Fields

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**Abstract** Accurate measurements of snow areas and surface albedo are crucial to advancing our understanding of the global climate system. This is because of the highly reflective nature of snow combined with its large surface coverage (snow can cover up to 40% of the Earth's land surface during the Northern Hemisphere winter). The reflectance of snow varies with both solar incidence angle and the viewing angle. Visible sensors with different spatial resolutions have been used to infer the snow parameters. Currently, only nadir-viewing directional reflectance data are available from satellite observations. Observations at multiple angles are needed to infer the hemispheric reflectance albedo of snow fields.

We propose to study the directional reflectance of snow fields using POLDER data, which contains information from different viewing angles and polarizations. POLDER was successfully launched on the ADEOS-1 satellite in August, 1996, however, because POLDER data are not yet available, data from ASAS, a pointable, airborne spectroradiometer, were used in this study. Data collected over Glacier National Park of Montana show strong angular dependence. Preliminary results confirm the anisotropic nature of the snow reflectance. Knowledge of the bi-directional reflectance function (BDRF) of snow-covered surfaces is the key to developing a true albedo model in the future.

**Key words** Snowpack, Albedo, BDRF

## 1 INTRODUCTION

The accumulation, distribution, structure and melt characteristics of the snowpack are largely affected by the regional energy balance. In turn, snow on the ground affects weather and climate, and the timing and amount of streamflow runoff. Through modeling, we will be able to improve our understanding of snow accumulation and ablation processes and thus, the snowpack energy budget.

The measurements provided by a remote sensor are primarily a function of the energy flux from the scene which is exiting in the direction of the sensor. This flux is dependent on the spatial, temporal, and angular distribution of energy fluxes entering the scene, and the spatial arrangement and properties of the types of matter within the scene. The critical remote sensing data required for studying the energy balance of a snowpack include snow extent, water e-

quivalent and albedo. Albedo is one of the most important parameters needed to model surface energy interactions. Snow albedo cannot be measured on a global scales, since spaceborne sensors presently only collect energy at narrow spectral bands and angles. However, it should be possible to infer albedo using data from a new breed of satellite sensors beginning in late 1990s.

Albedo is the energy reflected in all directions over the reflective part of the spectrum. Knowledge of the directional distribution of solar radiation reflected from snow surfaces is required to determine albedo because the anisotropic nature of the reflected radiation<sup>[1-3]</sup>. Reflectance of snow is greatest in the forward scattering direction due to specular reflection of snow crystals. Multiple reflections from the numerous ice crystals that comprise a snowpack cause the high reflectance of snow. For fresh snow, reflectance is nearly 100% in the visible region and decreases in the near infrared<sup>[4,5]</sup>. When surface

snow grain size and impurity increases, reflectance decreases, but the anisotropic reflectance of the snow-pack increases<sup>[6]</sup>.

Prior to POLDER data becoming available, ASAS data have been used to study the angular reflectance from the snow surface. ASAS provides a particularly useful source of information for surfaces with strong anisotropic characteristics. With ASAS, reflected solar radiances at different reflection angles can be measured over a large area in a short time interval. A handheld, pointable spectrometer has also been used to collect surface reflectance spectra for comparison.

## 2 STUDY AREA AND SENSORS

The study area consists of two sites in Glacier National Park in northwestern Montana, USA. Site 1 is located on a flat meadow adjacent to St. Mary Lake and site 2 is a large meadow located in the western part of the park near Polebridge, MT. The average elevation for site 1 and site 2 is about 1400 m and 1100 m, respectively. At site 1, shallow snow covered about 50% of the surface. Dormant grasses accounted for most of the remaining surface. At site 2, the snow cover was greater than 90%, with an average snow depth of 8 to 12 cm.

The Advanced Solid-state Array Spectroradiometer (ASAS) is a 29 spectral band radiometer collecting data between 462 and 865 nm wavelength with a spectral resolution of 15 nm<sup>[7]</sup>. It can image a target through a sequence of at least seven fore-to-aft view-zenith angles ranging up to 60° on either side of nadir. When an aircraft is flown at 4500 m above the surface, the sensor resolution at ground level is about 4.25 m. ASAS is radiometrically calibrated with an uncertainty of 6% attributable to the laboratory calibration procedures<sup>[7]</sup>. A neutral density filter was added because of the anticipated high brightness of the snow-covered sites.

ASAS scenes suffer geometric distortions due to the tilt angles, the scan rate, and aircraft motions. Consequently, the multiple sub-images in a scene are not registered to one another. Selection of sites on the

ASAS images is done visually. Digital data are extracted from the study sites and radiances may then be calculated<sup>[8]</sup>.

At ground level, high-resolution spectra from snow covered surface were obtained using a handheld SE-590 spectroradiometer<sup>[9]</sup>. The spectral data were taken during the NASA C-130 aircraft overflights of the test sites, thus the solar zenith angles for the ground-based and airborne data were very close to each other. The instrument has a 6° field-of-view giving a ground sampling area of approximately 15 cm in diameter at nadir and increasing with increasing viewing angle. A number of measurements were taken to provide reflectance spectra in the solar principal and perpendicular planes between -75° and +75°. Due to limited sighting of these test sites, reflectance data collected above 60° are subject to large errors.

## 3 RESULTS

On February 25 and 26, 1992, a ground crew, equipped with a spectrometer, and a NASA C-130 aircraft, equipped with the ASAS, collected data over the two test sites. Flight lines parallel and perpendicular to the solar principal plane were flown. Radiance data were atmospherically corrected using the 6S atmospheric radiative transfer code (reference) to give estimates of surface bi-directional reflectance, using an estimated aerosol optical depth of 0.035 at 550 nm, and a mid-latitude winter atmospheric model. Fig. 1 and Fig. 2 show the radiances for selected angles of the ASAS sensor over site 1 and site 2 parallel to the principal plane of the sun. The C-130 aircraft was flown in the direction away from sun, thus, negative tilt angles were looking toward sun. Effects of forward scattering (with negative tile angles) are obvious. Radiance differences larger than 20% were registered for measurements 60° toward the sun and 60° away from the sun. In the perpendicular plane the differences were smaller. The observed radiances are higher for site 2 than for site 1. This is consistent with the fact that site 2 had more snow than site 1.

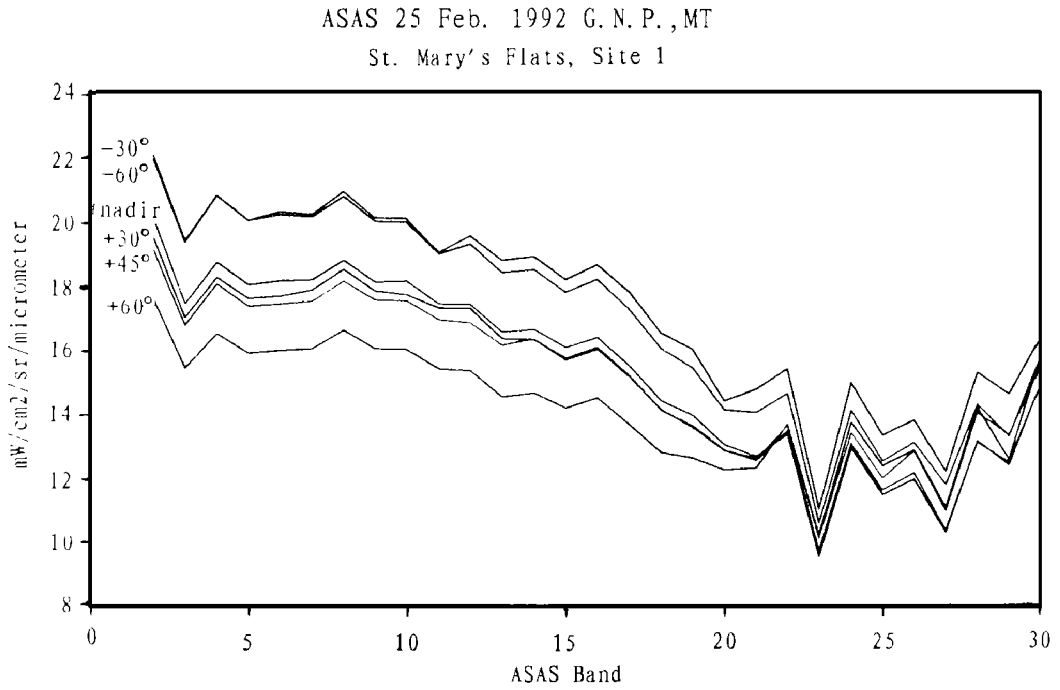


Fig. 1 Show the radiances for selected angles of the ASAS sensor over site 1

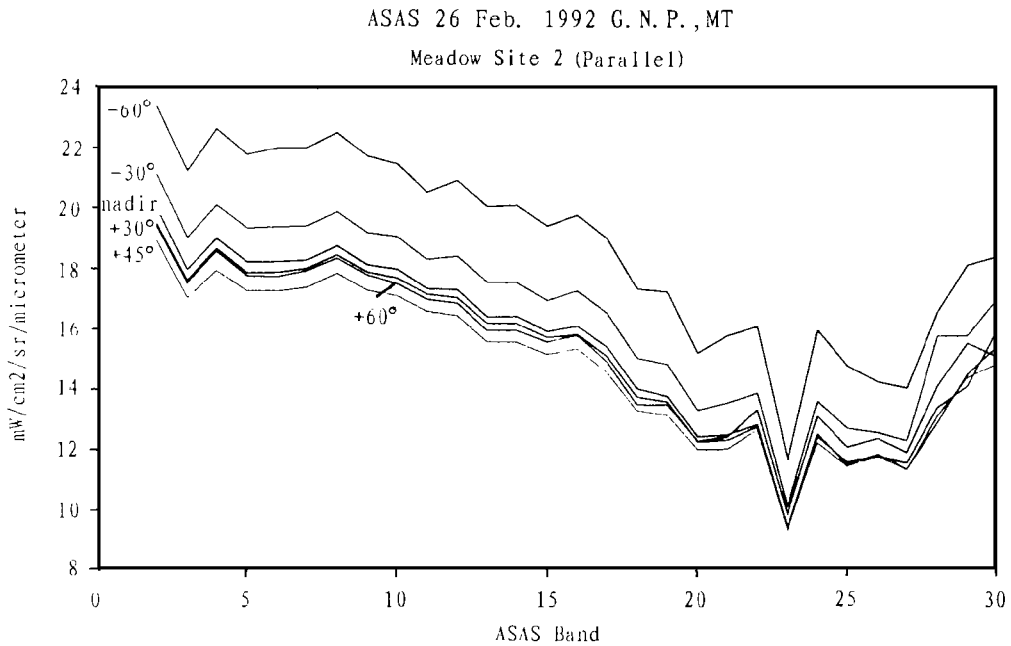


Fig. 2 Show the radiances for selected angles of the ASAS sensor over site 2

Fig. 3 and Fig. 4 show the reflectance of snow-covered and grass-covered surfaces with different incidence angles ( $+60^\circ$ ,  $+30^\circ$ ,  $0^\circ$ ,  $-30^\circ$ , and  $-60^\circ$ ) parallel to the principle plane of the sun. A halon target was used as a reference in calculating the surface reflectance. The reflectance factor varied from about 80% to 120% for the snow. For dormant grass, the

Prairie Snow

26 Feb. 1992 (Parallel)

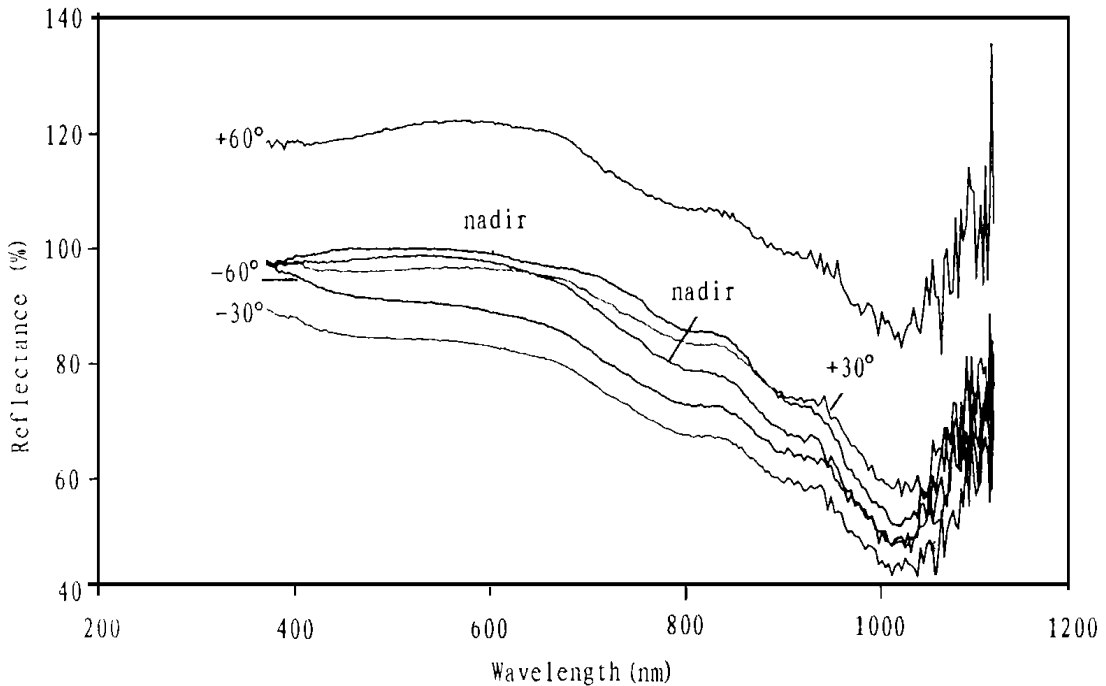


Fig. 3 Show the reflectance of snow-covered surfaces with different incidence angles parallel to the principle plane of the sun

To compare ASAS data derived reflectances with SE-590 observations, a small test area with  $10 \times 10$  ASAS pixels (about  $50\text{m} \times 50\text{m}$ ) was picked for each test site. The 6S model is used to translate the radiance into a reflectance factor. For the SE-590 data, the fractional surface coverage estimated by the ground crew was used to calculate the reflectance factor for a surface having a mixture of snow and dormant grass. Fig. 5 and Fig. 6 show the representative surface reflectance for site 1 and 2. Reflectance factors derived from ASAS are also plotted. At site 1, the match was good. For site 2, ASAS derived reflectance factors were about 10% lower than expected for a surface with 90% snow-cover and 10% dor-

mant grass. This discrepancy could very well be caused by the visual selection of the ASAS sample sites.

#### 4 SUMMARY

ASAS and SE-590 measured reflected solar radiances were used to study the directional reflection characteristics of snow-covered surfaces. A directional snow reflectance factor inferred from these data varied with the solar zenith angle and the surface snow characteristics. Mixtures of different surface types within a footprint will greatly affect the reflectance factor. Based on the knowledge gained in

this study, we will develop a method to estimate snow bi-directional reflectance using a Monte Carlo

solution of a hybrid, geometric optics/radiative transfer model.

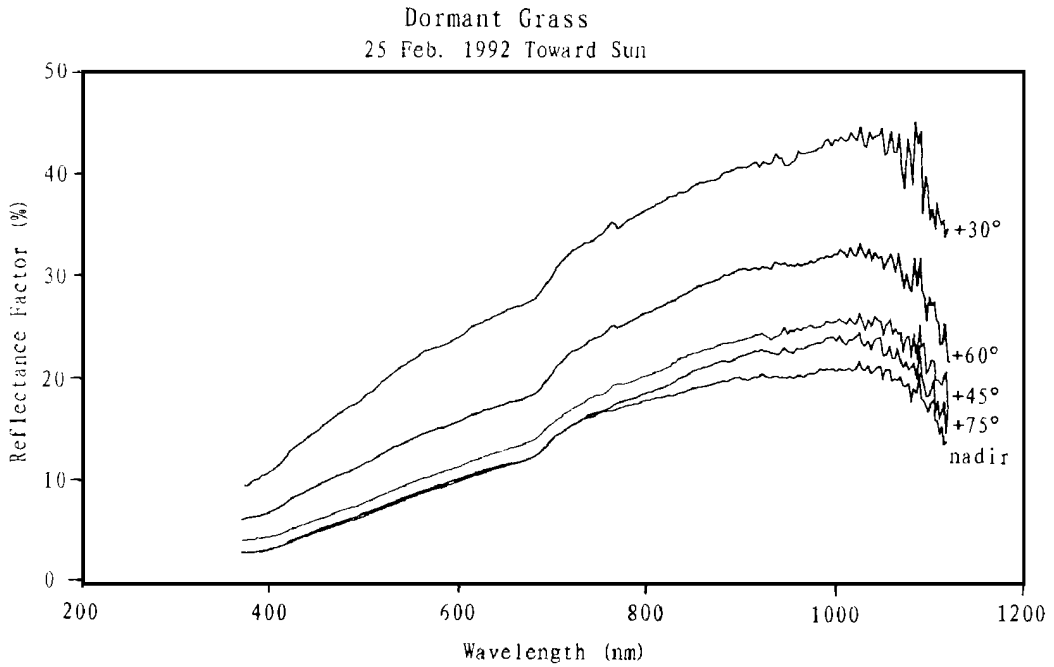


Fig. 4 Show the reflectance of grass-covered surfaces with different incidence angles parallel to the principle plane of the sun

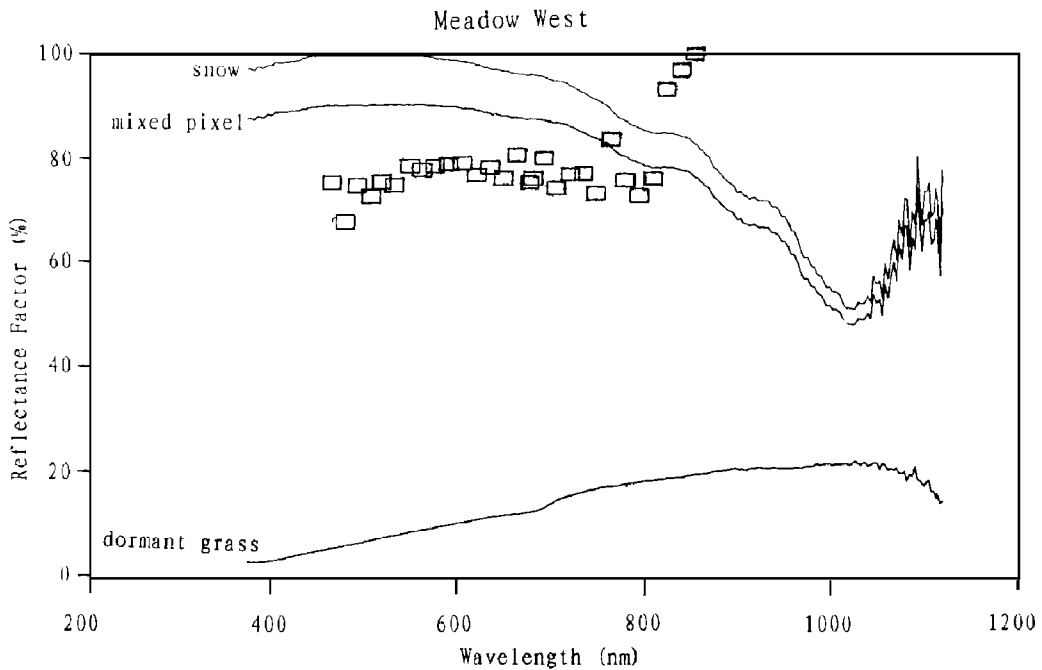


Fig. 5 Show the representative surface reflectance for site 1

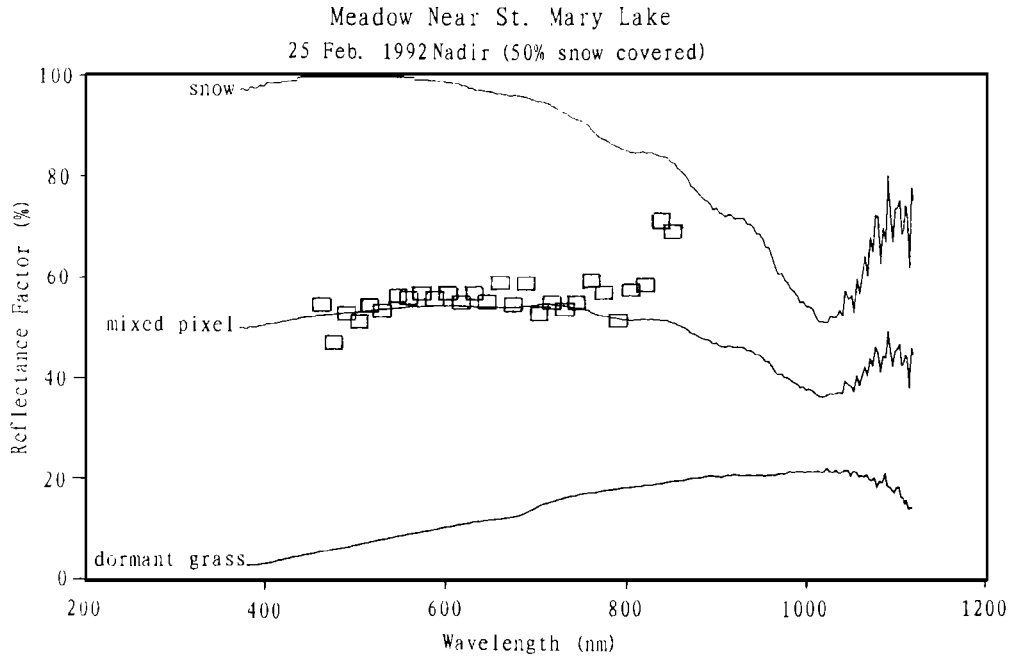


Fig. 6 Show the representative surface reflectance for site 2

## REFERENCES

- [1] Middleton, W. E., A. G. Mungall. The luminous directional reflectance of snow. *J. Opt. Soc. Am.*, 1952, **42**, 572-579.
- [2] Salomonson, V. V., W. E. Marlatt. Anisotropic solar reflectance over white sand, snow and stratus clouds. *J. Appl. Meteorol.*, 1975, **73**, 475-483.
- [3] Dirmhirn, I. F. D. Eaton. Some characteristics of the albedo of snow. *J. Appl. Meteorol.*, 1975, **14**, 375-379.
- [4] O'Brien, H. W., R. H. Munis. Red and near-infrared spectral reflectance of snow. In Rango, A., ed. Operational applications of satellite snowcover observations, (SP-391). Washington, DC, National Aeronautics and Space Administration, 1975, 345-360.
- [5] Dozier, J., S. R. Schneider, D. F. McGinnis. Effects of grain size and snowpack water equivalence on visible and near-infrared satellite observations of snow. *Water Resour. Res.*, 1981, **17**, 1, 213-221.
- [6] Dunkle, R. V., J. T. Bevans. An approximate analysis of the solar reflectance and transmittance of a snow cover. *J. Meteorol.*, 1956, **13**, 212-216.
- [7] Irons, J. R., K. J. Ranson, D. L. Williams, R. R. Irish, F. G. Huegel. An off-nadir pointing imaging spectrometer for terrestrial ecosystem studies. *IEEE Trans. Geosci. Remote Sensing*, 1991, **29**, 66-74.
- [8] Hall, D. K., J. L. Foster, J. R. Irons, P. W. Dabney. Airborne bi-directional radiances of snow-covered surfaces in Montana, USA.

*Annals of Glaciology*, 1993, **17**, 35-40.

- [9] Hall, D. K., J. L. Foster, A. T. C. Chang. Reflectance of snow as measured in-situ and from space in sub-Arctic areas in Canada and Alaska. *IEEE Trans. Geosci. Remote Sensing*, 1992, **30**, 634-637.
- [10] Dubreuil, M. A., M. Woo. Problems of determining snow albedo for the high Arctic. *Atmosphere-Ocean*, 1984, **22**, 379-386.

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Dr. Alfred T. C. Chang received his undergraduate education in Taiwan and the M.S and Ph.D. in Physics from the University of Maryland in 1970 and 1971 respectively. He was an NAS/NRC Resident Research Associate at NASA/GSFC from 1972 to 1974. He joined NASA/GSFC in 1974. His current position is Research Scientist with the Hydrological Sciences Branch of the Laboratory for Hydrospheric Processes at NASA/GSFC. His research expertise and experience include microwave remote sensing, microwave sensor systems and radiative transfer modeling of the atmosphere, rain, snow and soils. In 1988 Dr. Chang received the NASA Medal for Exceptional Scientific Achievement as a result of his microwave radiative transfer research. In 1993 he was appointed to be the deputy project scientist for EOS P. M. project. In 1996 he received the GSFC Exceptional Achievement Award for his contribution to NASA's Earth Science remote sensing programs. He is currently a member of the American Geophysical Union, American Meteorological

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## 雪盖方向反射的多角度测量

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**摘要** 雪域和表面反照率的精确测量对于推进人们认识全球气候系统非常重要。这是因为大面积雪盖的高反射特性（北半球的冬季，雪可覆盖到 40% 的陆地表面）。雪的反射随太阳光线入射角度和观测角度的变化而变化。我们已采用具有不同空间分辨率的可见光传感器来获得雪的参数。目前，从卫星观测器能获得的只是天底观测方向反射数据，因此需要用多角度进行观测来获得雪域的半球反射率。

我们建议用包括不同观测角信息和多极化信息的 POLDER 数据来研究雪域的方向反射。载于 ADEOS-1 卫星上的 POLDER 已于 1996 年 8 月成功发射。但目前仍不具备 POLDER 数据，我们研究采用的是从可定向的机载分光辐射谱仪获得的 ASAS 数据。从 Montata 冰河国家公园采集的数据显示出很强的角度依赖性。初步的结果证实了雪反射的各向异性。对雪盖 BRDF 认识是以后的发展真实反照率模型的关键。

**关键词** 雪盖，反照率，BDRF