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THE REFLECTANCE CHARACTERISTICS OF SNOW COVERED SURFACES

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ABSTRACT

An analysis of field measurements of the reflectivity of an open snow field has been undertaken to assist in the interpretation of the NOAA reflectivity zones.

INTRODUCTION

The seasonal and year-to-year variations of the areal extent of ice and snow cover have an important effect on the heat balance of the Earth and hence on the weather and climate. Detailed monitoring of the snow and ice extent can be used to help predict future weather patterns and can be used to detect incipient climate changes. A better knowledge of the snow and ice extent of the past several years for which satellite data are available can help in the understanding of the mechanisms involved in weather and climate changes. The purpose of this study is to develop data analysis techniques to most efficiently use available satellite measurements to determine and understand components of the surface energy budget for ice and snow-covered areas. The emphasis here is placed on identifying the important components of the heat budget related to snow surfaces, specifically the albedo and the energy consumed in the melting process. Currently, weekly ice and snow charts are prepared by NOAA from satellite observations which map areas into three relative reflectivity zones. At the present time, about 10 years of this data are available. By quantifying the relative reflectivity zones, a unique albedo data base can be developed.

There are several problems encountered in determining the albedo of snow-covered surfaces from satellite measurements. First, the type, density, and height of vegetation will affect the albedo of the scene and produce temporal variations as the amount of vegetation showing through the snow changes with time. The NOAA reflectivity classes are to a degree a consequence of differences in the underlying vegetation. Second, the reflectivity of the snow changes as the snow ages, melts, refreezes, etc. necessitating repetitive coverage. Third, the reflectivity of a snow surface and more importantly a mixed snow-vegetation surface is anisotropic and because the surface is viewed in a limited range of viewing angles and solar zenith angles, an algorithm must be derived to determine the total hemispheric reflectance from the measured bidirectional reflectance. Fourth, some satellite systems (NOAA, VHRR for example) measure radiance in only a small wavelength interval and the data must be extrapolated to the entire solar spectrum. Finally, measurements at the satellite include the effects of atmospheric scattering and absorption. If the surface albedo is desired, the data must be corrected for these atmospheric effects.

RESULTS

The correction for atmospheric effects was addressed previously (1) and quantitative estimates for the NOAA reflectivity zones were obtained from an analysis of NOAA 4 and 5 VHRR visible data. The albedo of the surface and atmosphere observed at the satellite was calculated from the radiance values obtained from the VHRR visible digital data. The "space" albedo clearly has a solar zenith angle dependence as can be seen from the values of the space albedo for areas which appeared to be completely snow covered in Fig. 1. This dependence was judged to be due to atmospheric attenuation. A simple correction was applied to the data to remove the atmospheric effects. It was assumed that the space albedo (As) can be expressed as:

$$As = Ag\, P_{\Delta\lambda}{}^{(m_{in} + m_{out})} \qquad (1)$$

where Ag is the surface albedo, $P_{\Delta\lambda}$ is the atmospheric transmission coefficient for the wavelength interval $\Delta\lambda$, and m_{in} and m_{out} are the air masses along the incoming and outgoing paths.

Applying Eq. 1 to the space albedos, estimates of the surface albedo were computed. Although the results are characteristic of only a limited wavelength band and still contain the effects of anisotropy, inspection of the sample scenes clearly show three brightness classes corresponding to NOAA ice and snow maps for the same period. Thus, for initial estimates of albedo values for the NOAA reflectivity zones, it is sufficient to assume that surface albedo for mixed scenes were obtained. Albedo values for the entire solar spectrum and for both pure snow and pure vegetation, estimates of the surface albedo for mixed scenes were obtained from this procedure are given below.

Zone 1: least reflectivity - albedo: 25 to 35%
Zone 2: moderate reflectivity - albedo: 35 to 55%
Zone 3: highest reflectivity - albedo: 60 to 70%

Reflectivity zone 3 corresponds to almost vegetation-free snow fields. The principal problem in determining the total hemispheric reflectivity over all wavelengths from a surface with these characteristics lies in establishing the degree of anisotropy as a function of wavelength. From such information one may then extend satellite reflectance data viewed in a limited range of angles and narrow wavelength bands to provide estimates of surface albedo. To address this problem, field measurements of an open snow field using the JPL Portable Field Reflectance Spectrometer were conducted in March of 1977 and April of 1978. The data included measurements in the spectral range of 0.45 μm to 2.55 μm, and, for a variety of solar zenith angles, data were obtained for five inclinations from the vertical and five azimuths with respect to the sun. The data were averaged over 30 wavelength intervals each with a $\Delta\lambda$ of 0.05 μm. For each of these intervals, the ratio of the reflectance at a given viewing angle to the reflectance at nadir was determined and charts showing the angular distribution of the relative reflectivity for several wavelengths intervals prepared. The results have some irregularities in the patterns believed to be due to an uneven surface of irregularities in the snow condition. However, a clear pattern emerges of a wavelength dependence in the angular distribution of reflectance with the strongest anisotropy observed in the near IR. A sample of the results is given in Tables 1 through 3.

TABLE 1

The ratio of the reflectance at the given inclination and azimuth to the reflectance at nadir for the NOAA VHRR band.

INCLINATION FROM NADIR	AZIMUTH (0° TOWARD THE SUN) 0	45	90	135	180
30	1.016	1.020	1.007	.977	1.007
45	1.007	1.015	.983	1.032	1.015
60	1.034	.981	.939	.974	1.014
75	1.039	.958	.944	.938	.938

TABLE 2

The ratio of the reflectance at the given inclination and azimuth to the reflectance at nadir for λ = 0.8 μm.

INCLINATION FROM NADIR	AZIMUTH (0° TOWARD THE SUN) 0	45	90	135	180
30	1.025	1.036	1.017	.993	1.015
45	1.021	1.024	1.004	1.041	1.032
60	1.060	1.000	.966	.999	1.045
75	1.078	.986	.974	.969	.973

TABLE 3

The ratio of the reflectance at the given inclination and azimuth to the reflectance at nadir for λ = 1.1 μm.

	AZIMUTH (0° TOWARD THE SUN)				
	0	45	90	135	180
30	1.077	1.113	1.044	1.035	1.032
45	1.101	1.077	1.064	1.074	1.071
60	1.177	1.083	1.057	1.057	1.113
75	1.250	1.121	1.054	1.051	1.055

The greatest spatial and temporal albedo variations are found in relectivity zones 1 and 2. Within these zones, the vegetation density and shadows largely determine the spectral character of the albedo. During April of 1978, NC-130B overflights with the Modular Multiband Scanner were conducted in the Donner Pass and Benten areas. An analysis of these data is in progress aimed at determining the relationship between vegetation density over snow and the albedo of a mixed forest, shadow and snow scene.

REFERENCE

(1) Batten, E.S., M. Morrill, and J. Soho, 1977: The Albedo of Snow Covered Surfaces Determined from NOAA 4 and 5 Satellites, Presented at the Spring 1977 AGU Meeting, Washington, D.C.

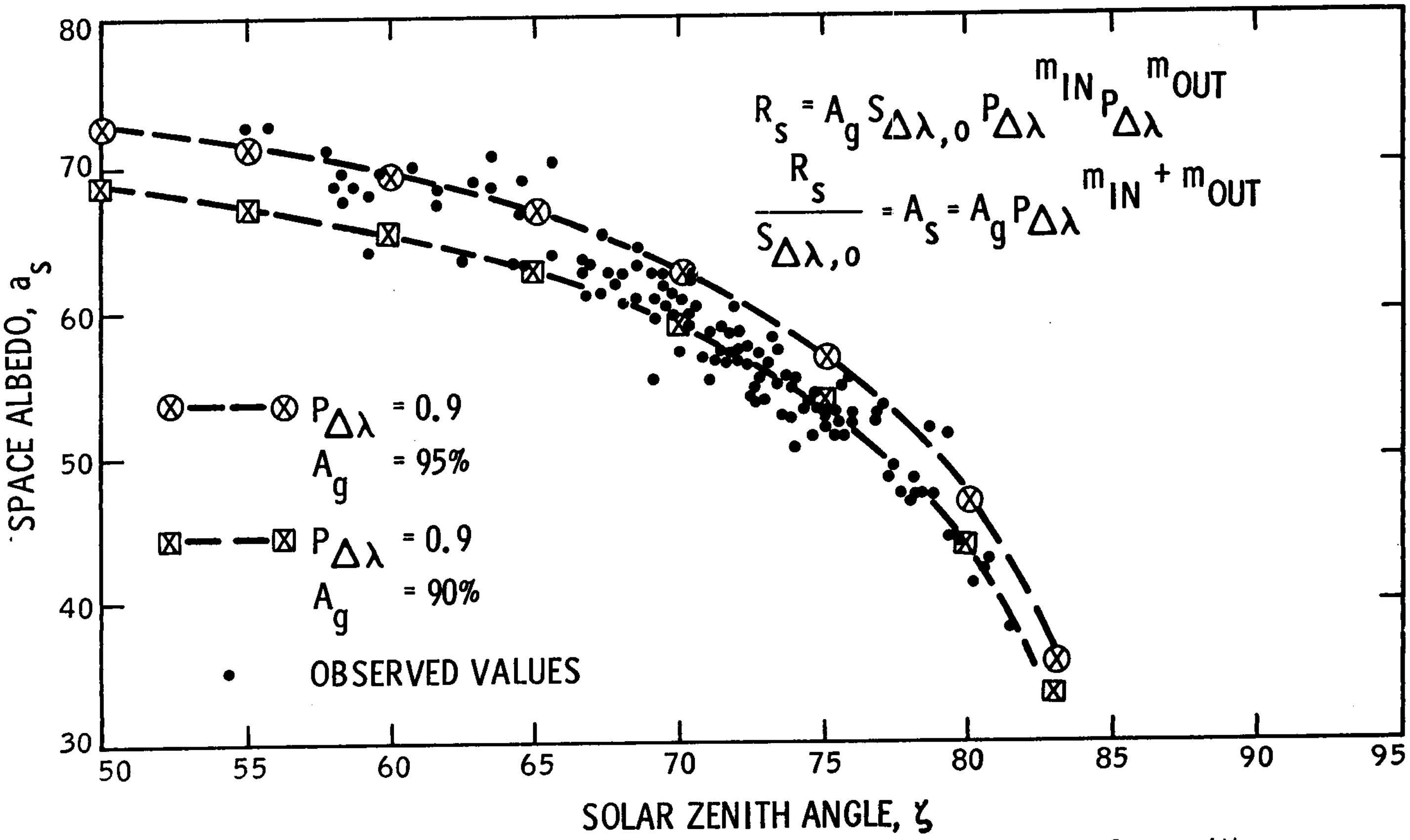

Fig 1 Observed and theoretical space albedo as a function of solar zenith angle as determined from NOAA 4 and 5 VHRR visible data.